DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 41

THE WINDMILL: ITS EFFICIENCY AND ECONOMIC USE, PART I.—MURPHY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1901

IRRIGATION REPORTS.

The following list contains titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a resumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps, showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; and "Construction of topographic maps and selection and survey of reservoir ites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts; Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; and "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE WINDMILL:

ITS EFFICIENCY AND ECONOMIC USE

PART I

BY EDWARD CHARLES MURPHY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1901

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, December 5, 1900.

SIR: I have the honor to transmit herewith a manuscript entitled The Windmill: Its Efficiency and Economic Use, Part I, by Edward Charles Murphy, formerly professor of civil engineering at the University of Kansas, and to request that it be published in the series of Water-Supply and Irrigation Papers.

This paper, with its complement, Paper No. 42, is a revision of Paper No. 8, printed in 1897, embodying additional data obtained by recent investigations. The demand for Paper No. 8 was so great and the practical applications of windmills to the problem of bringing water to the surface have been so extended that it has seemed desirable to make available the conclusions given in the following pages.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE WINDMILL: ITS EFFICIENCY AND ECONOMIC USE.

PART I.

By Edward Charles Murphy.

INTRODUCTION.

History does not record the name of the person who invented the windmill, nor give the date of the invention. The belief that windmills were used by the Romans is not well authenticated, and their use by the Bohemians in 718 is doubted. It is quite clear, however, that they were used in France and Italy in the twelfth century for grinding corn, and that they were used in Holland in the fifteenth century for pumping water over the dikes into the sea.

Mr. John Burnham, of Connecticut, is said to be the inventor of the American windmill. Mr. L. H. Wheeler, an Indian missionary, patented the Eclipse mill in 1867. The first steel mill was the Aermotor, invented by Mr. T. O. Perry in 1883.

The common European windmill, shown in section in figs. 1 and 2, differs much in appearance from the American mill. The wind wheel of the European mill has usually four long wooden arms, to each of which is attached a sail, against which the wind presses. The sails consist of a framework, on which canvas is stretched, usually forming a warped surface, the angle with the plane of the arms (called the angle of weather) being about 7° at the outer end and 18° at the inner end. The length of sail was usually about five-sixths the length of the arm, the width of the outer end one-third the length, and the width of the inner end one-fifth the length. The sail area is seen to be small compared with the wind area or zone containing the sails. The arms were sometimes 60 feet long. The American wooden mill is much smaller and more compact than the European mill. It has six or eight arms, to which is attached a framework carrying many small sails. These sails are usually 3 or 4 feet long, 3 or 4 inches wide at the outer end, and 1 to 3 inches wide at the inner end, and are set at an angle of 30° to 40° to the plane of the wheel. For large wheels these sails are arranged in two or more concentric rings. The American steel mill differs principally from the wooden mill in that it has larger and fewer sails for a given size of mill, its sails are curved instead of plane, and it offers less resistance to the passage of the air over the back of the sails. In the sails of the steel mill there is seen to be a partial return to those of the European mill.

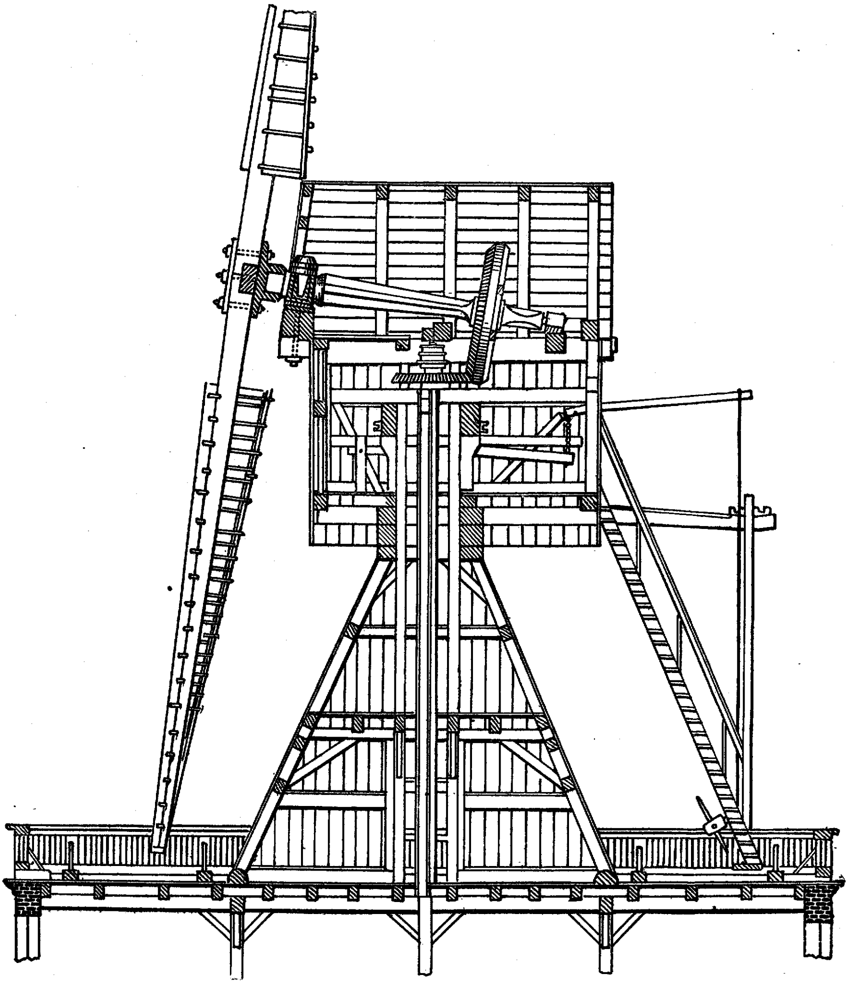

FIG. 1.—Section of common European post windmill mounted on central column.

CLASSIFICATION OF WINDMILLS.

Windmills may be divided into two general classes—paddle wheel and sail wheel. The Jumbo shown in Pl. XVI, *B* (Part II), and Little Giant No. 56, described on pages 125 to 127, Part II, are good illustrations of the first class. In both of these mills the sails move with the wind, and it is necessary to have a shield, or a method of feathering the sails, in order to keep the wind from striking them when they are moving in a direction opposite to that of the wind. In the Jumbo the axis of the wheel is horizontal, in the Little Giant it is vertical; but the wind acts on the sails of both in substantially the same way. The air acts with full pressure on only one sail of the Jumbo at any one time, and on half the sails it has no action, or only negative action.

In the sail-wheel mill (fig. 1, Part I, and Pl. XV, Part II) the wheel moves at right angles to the direction of the wind, instead of in the same direction, as in the paddle-wheel mill. The wind acts with a

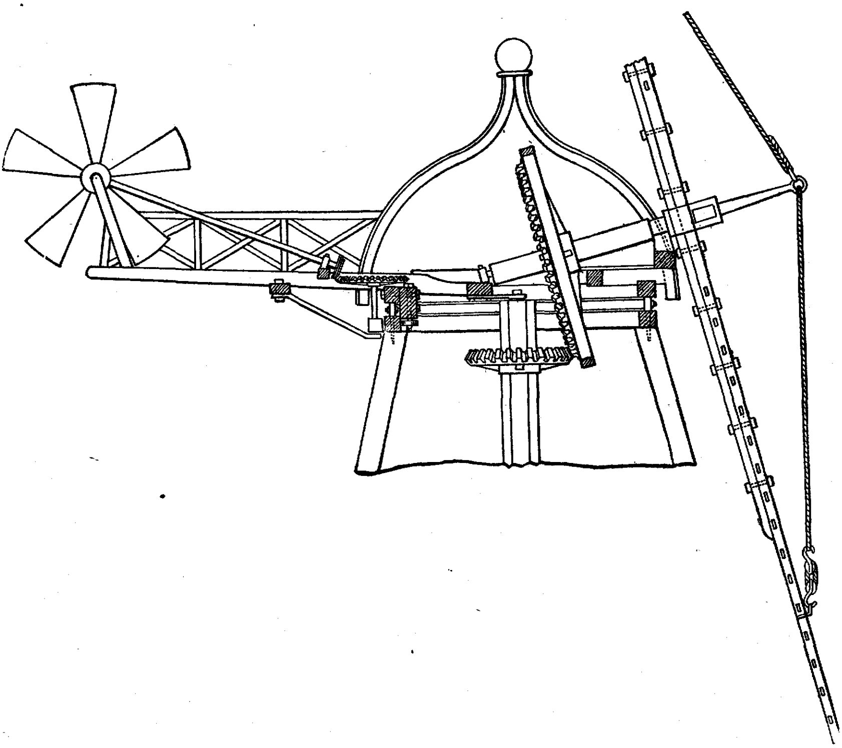

FIG. 2.—Early form of head of European tower windmill.

certain pressure on all of the sails all of the time. The circumference velocity of the sail wheel may be two or more times greater than the velocity of the wind that drives it, but the circumference velocity of the paddle wheel is always less than the velocity of the wind that drives it. The sails of the sail-wheel mill must be placed at an angle with the plane of the wheel, so that the wind will press on them; but the sails of the paddle-wheel mill may be in the plane of the axis of the wheel.

For greatest pressure on the sails of a sail-wheel mill the axis of the wheel must be parallel to the direction of the wind. It is necessary, then, for the wheel to change its direction as the wind changes. In the German or post mill the whole building, as well as the wheel, can be turned around on a post by hand. In the tower or Dutch mill the upper part only of the mill turns with the wheel. This is accomplished by hand in the mill shown in fig. 1, and by an auxiliary windmill in the mill shown in fig. 2. In the American mills the upper part only turns on a turntable, which is usually on rollers or balls. This is accomplished, first, by the pressure of the wind on a long rudder vane extending out behind the mill, and in some mills by a side vane as well; or, second, by the pressure of the wind on the wheel itself, which is placed on the opposite side of the tower, as in fig. 46, Part II; or, third, by side wheels, as in mill No. 52, fig. 50, Part II.

REGULATING DEVICES.

The wind is constantly changing in velocity as well as in direction, and if the load on the mill is constant the speed of the mill and of the machine which it operates will change with it. If the speed is to be kept nearly constant, some device is needed to reduce the wind pressure on the wheel when the wind velocity reaches a certain amount. In the European mill there are two methods of doing this, viz, by means of a brake or friction rings and by changing the sail area. The latter is accomplished by rolling or unrolling the canvas sails by hand or automatically. In the American mill the speed is regulated by changing the sail area in one of three ways: (*a*) By sections of the wheel revolving about an axis which places each sail at an angle to the direction of the wind less than 90°, as in fig. 36, Part II; (*b*) by placing the axis of the wind wheel eccentric to the axis of the tower, so that the wind pressure on the wheel will cause it to revolve around the axis of the tower; and (*c*) by the wheel moving naturally around the axis of the tower in the direction in which it is revolving. This turning action around the axis of the tower is counteracted by a spring or a weight, or, as we commonly say, "the wheel is held in the wind" by a spring or a weight. A weight is better than a spring, for by moving it out or in any desired pull can be placed on the wheel. A spring can not easily be adjusted and may lose some of its tension. The first method of regulation, called the centrifugal-governor method, is used in the Halliday mill (fig. 20) and in the Althouse-Wheeler mill (fig. 36, Part II). The second method is illustrated in the Aermotor (fig. 33, Part II), which shows the axis of the wheel eccentric to the axis of the tower by 4.5 inches. It also shows the spring which holds it in the wind. This spring also resists the action of the load, which tends to turn the wind wheel out of the wind. The third method is illustrated by the Woodmanse mill.

DUTCH WINDMILL AT LAWRENCE, KANSAS.

EARLY EXPERIMENTS.

Smeaton's experiments.—The first experiments of which we have any record were made by John Smeaton, an English engineer, and published in 1755 to 1763.[1] These experiments were made on model windmills of the European type, for the purpose of determining the best shape of sail for a given sail area. The models each had four arms 21 inches long. For one set of tests the sails were 5.6 inches broad and 18 inches long, giving an area of 403 square inches. In another set of tests the sails were 18 inches long, 5.6 inches wide at the inner end and 8.4 inches wide at the outer end, with an area of 504 square inches. The sails were either plane or warped at various angles. These mills were worked by moving the windmill around in a circle of 5½ feet radius, in still air, instead of placing them on a tower and allowing the natural wind to drive them. The wheel was moved around in this circle by means of a cord wound on a drum on a vertical shaft, the horizontal arm which held the wheel being fastened to this shaft. The work done by the wheel in a given time was measured by observing the length of string wound on the shaft of the wheel, a weight of known size being attached to the end of the string. The velocity of the wind, which was assumed to be the velocity of the end of the arm where the wheel was attached to it, varied from 4⅓ to 8¾ feet a second, or from 2.9 to 6 miles an hour.

It will be noticed that these wheels are only 3.5 feet in diameter, that they were moved in a circle only 5.5 feet in diameter, and that wind velocities or wheel velocities were small and of only a limited range—from about 3 to 6 miles an hour. Smeaton draws the following conclusions from his experiments:

(1) The velocity of the windmill sails, whether unloaded, or loaded so as to produce a maximum, is nearly as the velocity of the wind: their shape and position being the same.

(2) The load at the maximum is nearly, but somewhat less than as the square of the velocity of the wind: the shape and position of the sails being the same.

(3) The effects of the same sails at a maximum are nearly but somewhat less than as the cubes of the velocity of the wind.

(4) The load of the same sails at the maximum is nearly as their squares and their effects as the cubes of their number of turns in a given time.

(5) When the sails are loaded so as to produce a maximum at a given velocity of the wind, and the velocity of the wind increases, the load remaining the same: first, the increase of effect, when the increase of the velocity of the wind is small, will be nearly as the squares of those velocities; secondly, when the velocity of the wind is doubled, the effects will be nearly as 10 to 27.5; but, thirdly, when the velocities compared are more than double of that where the given load produces a maximum, the effects increase nearly in a simple ratio of the velocity of the wind.

(6) If sails are of similar figure and position, the number of turns in a given time will be reciprocally as the radius or length of the sail.

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[1] Philos. Trans. Royal Soc. London, 1755-1763.

(7) The load at a maximum that sails of a similar figure and position will overcome at a given distance from the centre of motion, will be as the cube of the radius.

(8) The effects of sails of similar figure and position are as the square of the radius.

(9) The velocity of the extremity of Dutch sails, as well as of enlarged sails, in all their usual positions, when unloaded, or loaded to a maximum, is considerably quicker than the velocity of the wind.

Regarding the ratio of the sail area to the wind area or zone containing the sails, he found that where the ratio was greater than 7 to 8 the power of the mill was decreased instead of increased. Regarding the proper shape of sail, he found that the warped sail was more effective than the plane sail. He also found the following six angles of weather at equal distances from the shaft outward advantageous: 70°, 71°, 72°, 74°, 77.5°, and 83°. He states that a difference of two or three degrees in the angles of impact makes little difference in the power of the mill.

Coulomb's experiments.—C. A. Coulomb, a French engineer, made some tests of the work done by a Dutch windmill used for extracting oil from rape seed at Lille, in Flanders. His observations were published in 1821.[1] The mill was 70.2 feet in diameter. It had four warped canvas sails, each 28.7 feet long and 6.6 feet wide; the width of canvas was 5.5 feet. The angle which the plane of sail made to the plane of the wheel varied from 30° at the inner end to 12° at the outer end. The wind velocity was measured by the use of feathers carried along by the wind. Two men were stationed 150 feet apart, on slight elevations, to note the time required for each feather to pass over this distance. The velocity of the wind striking the wind wheel was assumed to be that found from these feathers. In a 14.9-mile wind, and with the load ordinarily used, he found that the wheel made 13 revolutions per minute with all the canvas spread. From these data he figured the useful work done by the mill per minute to be 232,388 foot-pounds and the useless work expended in shock of stampers and friction to be 37,310 foot-pounds, or a total of 269,698 foot-pounds, equal to 8.17 horsepower.

Coulomb did not consider this a complete or satisfactory test of this mill. He did not control the working of the mill, but simply observed what it did when handled by the miller who extracted the oil. He tried to induce the owner to permit him to use the mill for a time for experimental purposes, but did not succeed.

It will be seen from what follows that even if we assume the wind velocity to be correctly measured, this test does not necessarily show the power of the mill, for we do not know that the load used was the proper load for the wind velocity. It shows what the mill was doing, not what it might do under a better loading.

[1] Theorie de Machines Simple, by C. A. Coulomb. Paris, 1821.

Griffiths's experiments.[1]—In 1891–92 Mr. J. A. Griffiths made tests of six windmills used for raising water, with the following results:

Results of windmill tests by J. A. Griffiths.

No.	Type of windmill tested.	Outer diameter of sail.	Inner diameter of sail.	Gross area of sail wheel.	Weather angle at outer end of sail.	Diameter of pump.	Stroke of pump.	Average head of water.	Load on pump, per stroke.*a*	Velocity of wind per hour.*b*	Velocity of mill per minute.*b*	Horsepower.*b*
		Feet.	*Feet.*	*Sq. ft.*	° ′	*In.*	*In.*	*Feet.*	*Ft.-lbs.*	*Miles.*	*Rev.*	
1	Toowoomba	22.3	8.3	39.20	18 47	5	6.75	25	120	4.3	5.0	0.018
								100	480	7.0	6.8	0.098
2	Stover	11.5	4.5	104.0	43	3	4	29.2	29.2	5.8	13.0	0.011
								61.2	61.2	6.5	13.3	0.025
3	Perkins	16.0	6.0	201.0	36	3	10.75	39.0	105.0	6.0	7.5	0.024
4	Althouse-Wheeler	14.2	4.5	157.0	30	3	*c*10	66.3	166.0	7.0	12.6	0.065
5	do	10.2	3.8	81.0	28	3	4⅝	38.7	51.0	8.5	20.5	0.028
6	Carlyle	9.8	4.2	80.0	50	3	4	30.7	30.7	6.0	12.5	0.012

a These pump loads have been computed for comparison of these results with others.
b At maximum efficiency.
c Pump is double acting; this is twice the length of stroke.

No. 1 was a 22.5-foot wooden mill, with 20 warped sails each 87 by 36 by 9 inches, the weather angle at the outer end being 18° 47′ and at the inner end 40° 20′. It worked a direct-acting single-stroke pump having a 5-inch cylinder and 6.75 inches stroke. Two lifts were used, one of 25 feet and the other of 100 feet.

No. 2 was a 12-foot Stover wooden mill, having a wind wheel somewhat like that of mill No. 38. It had 112 sails, each 43 by 3.75 by 1.5 inches, set at an angle of 43° to the plane of the wheel. It worked a direct-acting single-stroke pump having a 3-inch cylinder and 4 inches stroke. The lifts were 29.2 and 61.2 feet.

No. 3 was a 16-foot Perkins solid wood wheel, the wind wheel having 160 sails, each 60 by 4 by 1.5 inches, set at an angle of 36° to the plane of the wheel. It worked a direct-acting double-stroke pump having a 3-inch cylinder and 5.375 inches stroke. The lift was 39 feet.

No. 4 was a 14-foot Althouse-Wheeler wooden sectional mill, the wind wheel having 104 sails, each 48 by 4 by 1.5 inches, set at an angle of 30° to the plane of the wheel. It worked a direct-acting double-stroke pump having a 3-inch cylinder and 5 inches stroke. The lift was 66.3 feet.

No. 5 was a 10-foot Althouse-Wheeler wooden sectional mill. The wind wheel had 84 sails, each 38 by 3.75 by 1.5 inches, set at an angle of 28° to the plane of the wheel. It worked a direct-acting single-stroke pump having a 3-inch cylinder and 4.625 inches stroke. The lift was 38.7 feet.

No. 6 was a 10-foot Carlyle iron mill. It had 7 somewhat spoon-shaped sails, each having a spout-like extension through which the

[1] Windmills for raising water, by J. A. Griffiths: Proc. Inst. Civ. Eng., Vol. CXIX, p. 321.

air flowed. It worked a direct-acting single-stroke pump having a 3-inch cylinder and 4 inches stroke. The lift was 30.7 feet.

The wind velocity was measured with the "f" wind gage, which was either on a tower near by or on an arm projecting as far as possible to windward. It appears that it was necessary to be near the gage in order to read the velocity, which would indicate a possible error in wind velocity and some interference with the wind striking the wind wheel. The range of wind velocities is not stated, and not more than two loads were used in any case.

These results will be compared with others further on.

King's experiments.[1]—Prof. F. H. King conducted a series of experiments with a 16-foot geared Aermotor, covering a period of one year—from March 6, 1897, to March 6, 1898. This mill was used to work one or more of four pumps: (1) A reciprocating piston pump with a 14-inch cylinder and 9 inches stroke; (2) a bucket pump having a normal capacity of 120 gallons per minute; (3) a No. 2 Gould centrifugal pump; and (4) the smallest size Menge pattern centrifugal pump. The bucket pump was used nearly all of the time. The reciprocating piston pump was used occasionally by itself and part of the time with the bucket pump, when the wind velocity was strong enough to carry both. The Menge was used occasionally with the piston pump and the bucket pump, when the wind velocity was strong enough to carry all.

There was no automatic device for throwing into or out of use any of these pumps. It was necessary to do this by hand, so that a part of the time the load on the mill was not suited to the wind velocity. This can be seen from the record. For example, on February 10, from 1 to 7 p. m., the wind velocity varied from 9 to 12 miles an hour and 8.6 tankfuls of water were pumped, while on June 1, from 8 a. m. to 4 p. m., the wind velocity varied from 11 to 15 miles an hour, and not a tankful was pumped. The report gives the number of tankfuls of 141.2 cubic feet which were lifted 12.85 feet each hour during the year, and some interesting conclusions drawn from these records.

Professor King has also made some tests of this mill with a Prony friction brake. The results of these tests, and the indicated horsepowers computed from them, are as follows:

[1] Bull. No. 68, Wisconsin Agricultural Experiment Station.

Results of tests of 16-foot geared Aermotor.

Wind velocity per hour.	Direction of wind.	Indicated horse-power.	Average wind velocity.	Average horse-power.	Barometer.	Temperature.
Miles.			*Miles.*		*Inches.*	*Degrees.*
8.4	SW.	0.2715	8.4	0.2715	29.40	0.0
12.0	----------	0.5791			29.36	0.5
12.4	----------	0.7230	12.33	0.5858	29.36	0.5
12.6	----------	0.4553			29.36	0.25
13.2	SW.	0.6213	13.2	0.6213	29.40	0.5
14.6	SW.	0.7343			29.36	−0.5
14.6	----------	0.9449	14.68	0.8602	29.40	0.5
14.8	SW.	0.9016			29.40	1.0
18.6	NW.	2.054	18.70	1.873	28.86	9.0
18.8	SW.	1.692			29.40	1.0
21.2	SW.	2.593			29.40	1.5
21.6	W.	3.715	21.55	3.033	29.06	−2.0
21.6	N.	3.227			28.86	7.0
21.8	NW.	2.597			----------	----------
22.0	W.	4.326			29.09	1.0
22.0	W.	4.236	22.06	3.652	29.04	−2.0
22.2	NW.	2.394			----------	----------
23.0	W.	3.842	23.00	3.996	29.07	−1.0
23.0	W.	4.151			29.05	−1.0
24.0	----------	5.983	24.30	4.768	28.75	6.8
24.6	W.	3.554			29.09	1.5
25.2	W.	4.882	25.2	4.882	29.09	1.5
27.3	N.	4.092	27.16	4.471	28.66	6.3
27.0	W.	4.850			29.10	1.5
39.0	N.	5.953	39.0	5.953	28.69	6.5
40.0	----------	5.971	40.0	5.971	28.69	6.3

This mill is similar to our 16-foot Aermotor No. 44, described in Part II. It will be seen later that the power found by Professor King is much greater than we have found it for high wind velocities. The probable reason for this difference will be discussed later. It may be stated here, however, that Professor King measured the wind velocity with an anemometer in a fixed position 40 feet due east of the windmill, and it will be seen that the wind was from the west, northwest, or southwest nearly all of the time when the brake tests were being made. (The wind came from the north around by the east to the south only three times while the brake tests were in progress.) The revolving wheel must have interfered with the running of the anemometer and caused it to show a less wind velocity than really existed.

Professor King also determined the work done by the mill in grinding corn. The power of the mill in a given wind velocity can not, however, be judged from these tests, since the grinder load was probably not suited to all wind velocities.

Results of brake tests of 16-foot geared Aermotor.

Wind velocity per hour.	Indicated horse-power.	Wind velocity per hour.	Indicated horse-power.
8 miles	0.25	26 miles	4.82
10 miles	0.40	28 miles	5.14
12 miles	0.56	30 miles	5.40
14 miles	0.78	32 miles	5.61
16 miles	1.08	34 miles	5.76
18 miles	1.62	36 miles	5.87
20 miles	2.39	38 miles	5.95
22 miles	3.31	40 miles	5.97
24 miles	4.31		

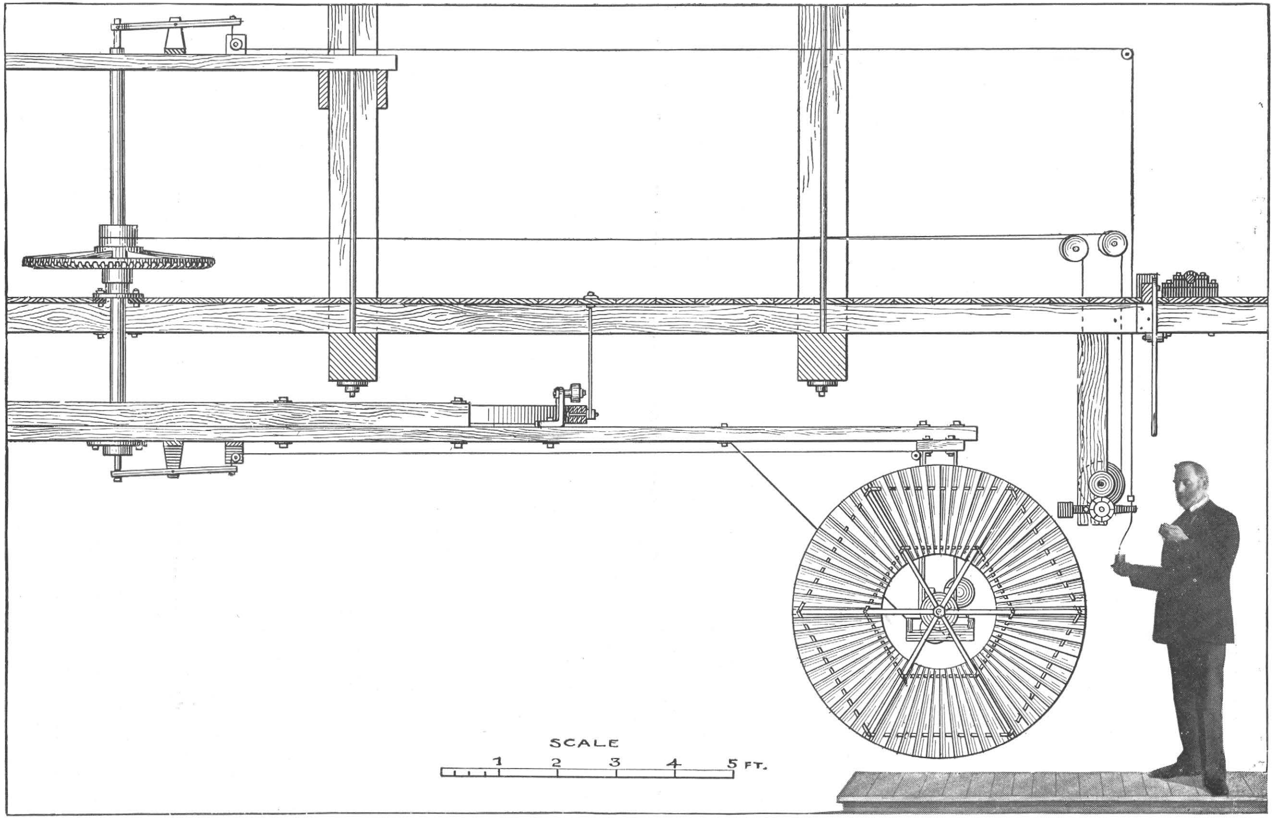
Perry's experiments.—From June, 1882, to September, 1883, Mr. T. O. Perry made experiments with 61 windmills, each 5 feet in diameter. The results were published in 1889.[1] Mr. Perry's methods were similar to those employed by Smeaton—he used small wheels moved against still air in a circle of 14 feet radius. His experiments were made on a much larger scale than Smeaton's, however, and his apparatus was more perfect. Smeaton used wheels of European type; Mr. Perry used those of American type. Pl. II is an elevation of Mr. Perry's apparatus, showing the wheel as it revolved about the vertical shaft, driven by an 80-horsepower engine. The power was measured by means of a Prony friction brake placed on a brass cylinder on the wind-wheel shaft. In order to eliminate the effect due to differences in the condition of the air, and get results comparable with one another, Mr. Perry used one of his wheels as a standard with which to compare the others. After the best load for a wheel had been obtained, comparative tests were made with this one and with the standard wheel, by trying first one wheel and then the other until several measurements of each had been taken. The final result of each wheel was the average of eight or ten measurements.

In comparing Smeaton's results with his own, Mr. Perry writes:

> We were not able to obtain the best results with weather angles as small as Smeaton's in any of our wheels. Nor did our sail speeds, as compared with wind velocity, nearly approach the speeds obtained by Smeaton. Even our unloaded wheels did not show the sail speed attained by the best of Smeaton's when loaded for maximum work. * * * Our loads at the maximum of work were smaller as compared with the greatest loads, and the speed of revolutions at maximum work as compared with the speeds of unloaded wheels, were smaller for our mills than for Smeaton's.

He states, however, that the general conclusions drawn by Smeaton (see pages 15 to 16) were substantially confirmed by his experiments. The difference between his results and Smeaton's he attributes to the differences in the mills used.

[1] Water-Supply and Irrigation Paper U. S. Geol. Survey No. 20.



ELEVATION OF APPARATUS USED BY PERRY IN WIND-WHEEL TESTS.

Some of Mr. Perry's conclusions are as follows:

(1) There is nothing gained by having the sail area more than seven-eighths of the wind area, and there is little gained by having it more than three-fourths of the latter area.

(2) That the power varies as the cube of the wind velocity.

(3) That the load for maximum power varies as the square of the wind velocity.

(4) That the speed of the unloaded wheel increases somewhat faster than the wind velocity.

(5) That the best speed for most of his wheels was about 0.55 per cent of the unloaded speed.

(6) That the conical deflector at the center of the wheel does not increase the power.

(7) That obstructions on the back of sails greatly reduce the power of the mill.

(8) That the speed of wheel No. 48 was increased 48 per cent by removing the strip from the back of each sail.

(9) That a deflector in front of the wheel increased the speed of a slow-moving wheel.

(10) That a deflector in front of the wheel did not increase the speed of a rapidly moving wheel.

(11) That a mast offers more obstruction in front of a wheel than behind it.

EXPERIMENTS BY WRITER.

The tests of windwills described in the following pages were begun by the writer in the summer of 1895. They were continued during the summer of 1896, with much better facilities than during the previous season. The results obtained to that time were published in Water-Supply and Irrigation Paper No. 8, entitled Windmills for Irrigation. Since then the work has been continued as time could be spared—mainly during a portion of three summer vacations. The work of the summer of 1896 was confined mainly to pumping mills. The tests show what each windmill and its pump were actually doing under certain conditions of load, lift, etc. They do not show what the mill might do under other conditions. It was evident that the useful work of a mill varied with its load and the efficiency of the pump. The latter could not well be ascertained. It was, therefore, thought best to confine the tests principally to power mills, in which the unknown factor of pump efficiency is not present, and where the load on the mill can easily be varied. This has enlarged the scope of the work, making it cover windmills for power as well as those for irrigation.

Many of our tests of pumping mills were made in the vicinity of Garden, Kansas. Perhaps nowhere in the United States is irrigation from wells by the use of windmills carried to the same extent as there, where may be found hundreds of windmill pumping plants furnishing water to irrigate from 1 to 15 acres each and lifting from 3 to 14.5 quarts per stroke to a height of from 10 to 45 feet, as well as large steel mills running day and night, when the wind is strong enough, and working pumps of the best kind.

SCOPE OF TESTS.

There are many makers of American windmills, and with the great variety of mills in use—no two are alike, though in some cases the difference is slight—it was impossible to test a mill of each type. It was our purpose to test only the mills that were in good working order and subject to good wind exposure, and which would add new data to that already obtained or confirm in some particular that previously secured. In some cases two or more mills of the same size and make were tested to show as far as possible the effect of pump, well, etc. on the useful work. The parts of mill and pump on which the power depends were carefully measured. The temperature and barometric pressure were observed in each case and the mean given. The discharge of pump per stroke was measured when possible, and the diameter of cylinder and length of stroke are given, so that the discharge can be compared with the figured displacement. The lift was measured whenever the surface of the water in the well could be reached with a tapeline. The number of strokes of the pump per mile of wind was found for velocities from 6 or 8 miles to 20 or 30 miles an hour. In some cases the number of strokes is given when no water was being pumped. In fact, there was collected for each mill as much data as it was conveniently possible to obtain which would in any way affect the power of the mill or be of interest.

PUMPING MILLS.

The essential difference between pumping and power mills is that in the former there is a pump rod with an up and down motion, while in the latter there is a vertical rotating shaft. The former is usually geared back 2 or 3 to 1, while the latter is generally geared forward 6 or 8 to 1. The ordinary pumping mill, such as is used for stock purposes, is lighter than the power mill, but the irrigating mill is of nearly the same weight as the power mill. The larger power mills have a pumping attachment, so as to work a pump as well as a grinder or other machine.

WELLS NEAR GARDEN, KANSAS.

A brief description of the water supply and wells of this locality may be helpful in considering what follows.

The water is found in sand and gravel at distances below the surface varying from 8 to 40 feet. This material is in layers of variable thickness and different degrees of coarseness, ranging from fine sand to large gravel. It is overlain by a layer of sandy clay, which in some places will for years stand vertical without any support; in other places there is very little clay in this layer. The wells are usually 3 to 4 feet square, and are cased with wood through the top sandy clay to the water-bearing sand; then a wood or galvanized-iron casing from 12 inches to 3 feet in diameter extends down from 8 to 20 feet into the sand to a layer of gravel. Where this latter casing is large, three or more galvanized-iron pipes 6 to 12 inches in diameter are put down in the bottom of it, and these sometimes have wire gauze over their tops to keep down the sand; they also have perforations about one-fourth of an inch in diameter for a distance of 2 feet or more from the bottom to admit the water. In many cases, instead of this small open well, the supply pipe is on a well point having the same diameter as the supply pipe, its length varying with the diameter. These well points have not given satisfaction and are being replaced by open wells.

On examining well points that have been used for a time it was found that many of the little openings through which water is admitted to the pump had become filled with fine grains of sand, thus reducing the area. Although this water area was of the proper amount when the well was new, it becomes too small after the well has been used for a time or after it has stood without being used. If this area is too small to allow the free passage of water into the pump, an added load is put on the latter.

PUMPS.

Nearly all of the pumps in use in the vicinity of Garden are of the reciprocating-piston type. Fig. 8 shows the Stone pump, manufactured by R. G. Stone, of Garden. This pump is made in three sizes—6 inch, 8 inch, and 10 inch, these dimensions being the approximate diameter of the discharge pipe. The diameter of the cylinder is less than the diameter of the pipe by twice the thickness of the brass lining. The valves (shown in fig. 9) are of the latest pattern. The plunger valve is of the single-flap or clack variety and the check valve is of the disc variety, made so that the water can pass up the center as well as around the sides. In an earlier form of this pump the plunger valve is of the double-flap or butterfly type and the check valve of the lift type, but with no opening at the center. Probably nine-tenths of the pumps in use near Garden are of the Stone variety.

Fig. 3 shows the Gause pump, one of the first pumps used there for irrigating purposes. It is more expensive than the Stone pump, and is not now so much used. Fig. 16 shows the cylinder of an 8-inch Frizell pump, a few of which are in use. Fig. 5 is a sectional view of the Woodmanse pump, which is used with mill No. 2. Pl. X, *B*, shows a crude homemade pump called the "water elevator." One of these is in use in Garden.

The efficiency of reciprocating pumps like those described varies directly with the lift, inversely with the number of strokes per minute, and with the design of the pump. For lifts of 10 or more feet and not more than 30 strokes per minute the efficiency in a good pump should be at least 70 per cent.

Prof. O. P. Hood[1] has measured the efficiency of two Frizell pumps—one 6 inch, with 14.1 inches stroke, like that shown in fig. 16, and one 4 inch, with 24 inches stroke, having a butterfly discharge valve. He found that for a 7.7-foot lift the efficiency of the 6-inch pump dropped from 75 per cent to 63 per cent as the number of strokes increased from 10 to 60 per minute; that for a 22.7-foot lift it decreased from 86 per cent to 82 per cent for the same range of speed; and that for a 37.8-foot lift it decreased from 84 per cent to 82 per cent, while the number of strokes increased from 10 to 50 per minute. The efficiency of the 4-inch pump dropped from 66 per cent to 60 per cent for a 12.8-foot lift, and from 83 per cent to 73 per cent for a 37.6-foot lift, as the number of strokes increased from 10 to 50 per minute.

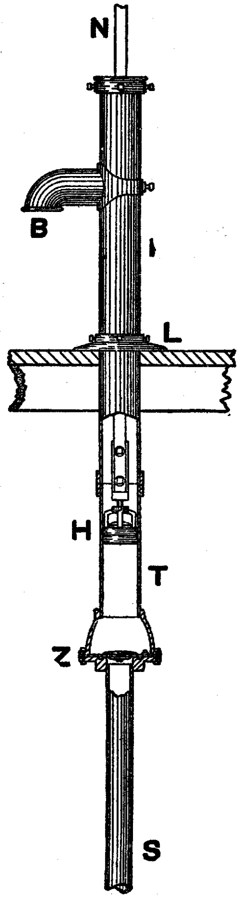


FIG. 3.—Gause pump. *N*, plunger; *B*, spout; *F*, discharge pipe; *H*, plunger; *T*, cylinder; *Z*, enlarged valve opening and check valve; *S*, suction pipe.

The valve area should be not less than 30 per cent of the cylinder area. The cylinder should be placed as near the water as possible; if it is more than 25 feet above the water, and the number of strokes is 30 or more, the cylinder will not fill properly, and pounding will result.

INSTRUMENTS AND METHODS.

The wind velocity was measured with a United States Weather Bureau cup anemometer, each mile of wind being recorded electrically by one pen of a 2-pen register. By means of a little device fastened to the pump an electric circuit is closed at each stroke of the pump and a record made by a recorder. Another electric circuit, leading from the recorder to the other pen of the register, is closed at each hundred strokes of the pump and a record made on the register. Hence the graphic record of the register shows the number of miles of wind in any given time, also the number of hundred strokes of the pump in the same time. The anemometer was held on a pole at the height of the axis of the wheel of the windmill. The pole was made so that its length could be increased at will from 25 to 50 feet. The anemometer on the pole is shown in Pls. III and XI.

[1] Water-Supply and Irrigation Paper U. S. Geol. Survey No. 14.

The discharge of the pump per stroke was ascertained by catching the water for several strokes in a tub and measuring it with a quart measure. In a few cases it was found to vary with the number of strokes per minute. Where it varied the discharge given is for a nearly maximum speed of pump.

The lift, or distance from the surface of the water in the well to the center of the water column as it leaves the discharge pipe, was measured when the pump was working quite rapidly. For pumps on well points it was estimated from the depth to water when the point was put down, making an allowance for the lowering of the water.

Each mill tested is described and the results of the tests given in tabular form. Nearly all of the mills are illustrated.

The number of strokes of the pumps per mile of wind and the horsepowers of the mills are in most cases explained by diagrams, which show at a glance the facts which otherwise can be comprehended only by a careful analysis of the tables. In these diagrams (figs. 6, 10, 11, 12, 13, 15, 17, 18, 19, and 21) the relation between the wind movement, in miles per hour, and the number of strokes made by the pump while the wind was moving over 1 mile is shown by the curved line. The space from left to right is proportional to the number of strokes of the pump. The data expressed by these diagrams were obtained directly from the record given by the anemometer register.

In explanation we will assume that the pen connected with the anemometer makes three short marks (3 miles) in fifteen minutes, indicating a mile in five minutes, or at the rate of 12 miles an hour. At the same time the other pen connected with the pump, and registering each 100 strokes, makes, say, two short marks, showing that the pump has made 200 strokes for this 3 miles of wind movement, or 67 strokes to the mile. This fact is entered on the diagram by a small circle placed at a distance from the right which corresponds to a wind velocity of 12 miles an hour, and at a distance from the bottom which corresponds to 67 strokes of the pump. In this way each observation is indicated. When the points have been plotted, the smooth curve is sketched so as to occupy an intermediate position among them.

In order to obtain the number of strokes more accurately than by measurement on the register sheet, they were actually counted for a considerable number of observations in each test. The number of strokes per minute is obtained by dividing the number of strokes per mile of wind by the number of minutes required to make the mile. For example: If the number of strokes per mile in a 12-mile wind (which requires $60 \div 12$, or five minutes to make a mile) is 90, then $90 \div 5 = 18$, the number of strokes per minute. The number of gallons raised per minute is found by multiplying the number of gallons per stroke by the number of strokes per minute. The horsepower of the mill in any wind velocity is found by multiplying the number of

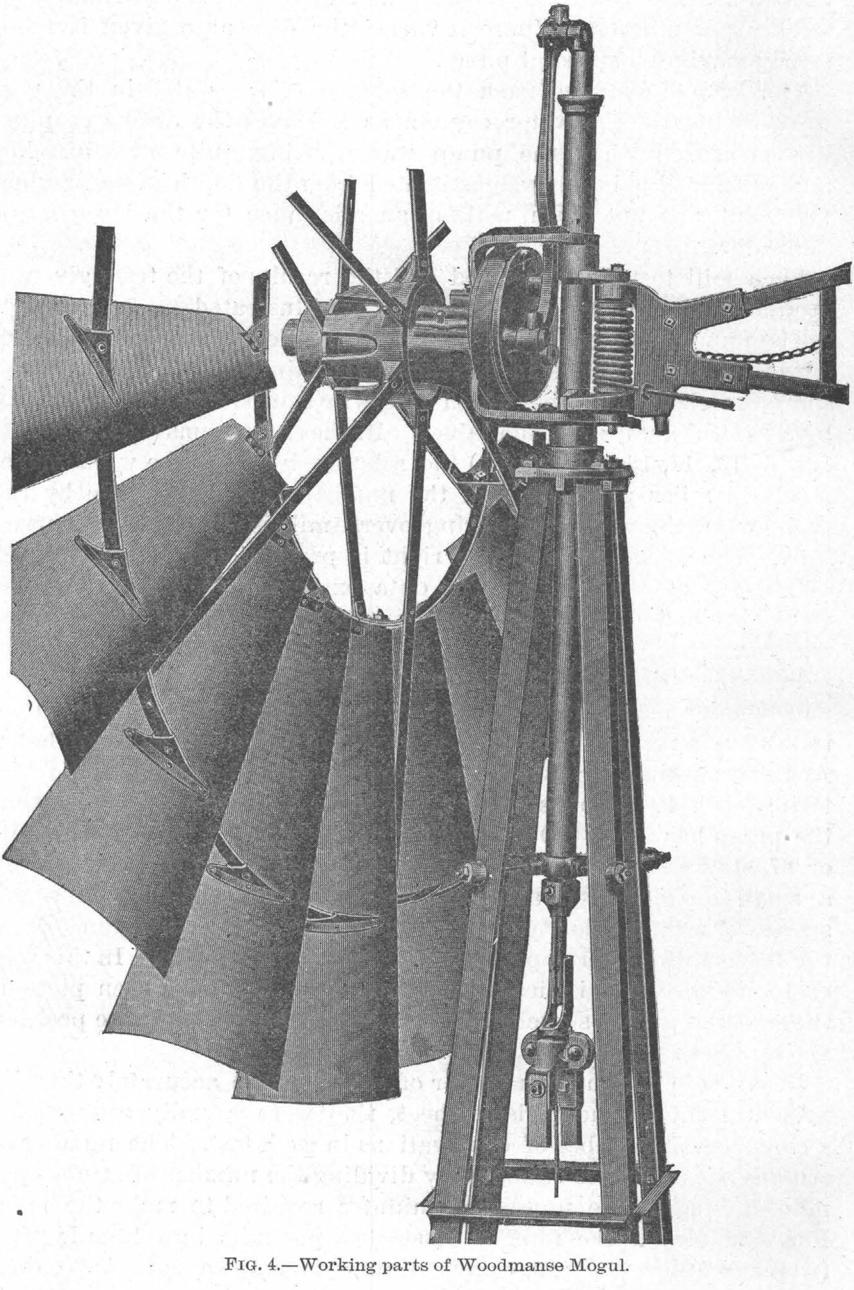


FIG. 4.—Working parts of Woodmanse Mogul.

gallons per stroke by the number of strokes per minute, then by 8.3 pounds (the weight of one gallon of water), then by the lift, in feet, and dividing the product by 33,000 (the number of foot-pounds in a horsepower), or by the following formula:

Horsepower $= nqgh \div 33{,}000$, where $n =$ number of strokes per minute, $g =$ the weight of one gallon of water, $q =$ the number of gallons per stroke of pump, $h =$ the lift, in feet. The pump load is the weight of water lifted per stroke multiplied by the lift, or height to which it is raised. The number of revolutions of the wind wheel per minute is found by multiplying the number of strokes per minute by the number of revolutions per stroke.

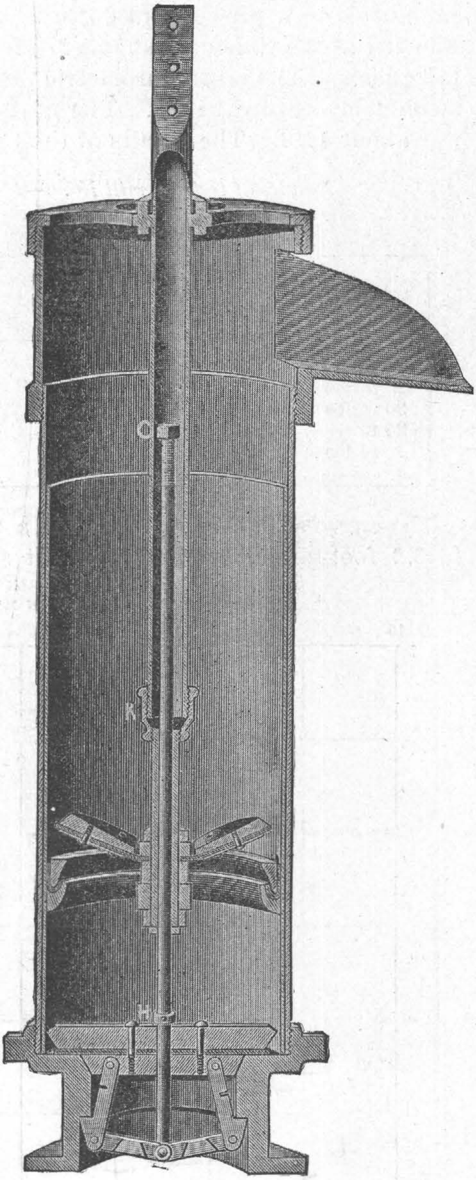


FIG. 5.—Sectional view of Woodmanse pump.

PUMPING MILLS TESTED.

Mill No. 1.—The tests of this mill were preliminary or experimental, being made for the purpose of perfecting the instruments employed, and were not completed for discussion.

Mill No. 2.—This is a 12-foot Woodmanse Mogul, manufactured by the Woodmanse-Hewitt Manufacturing Company, of Freeport, Illinois. Pl. III shows the mill, tower, pump, and pond, and fig. 4 the working parts. The tower is of steel, 50 feet high to the axis of the wheel. The wind exposure on the north is not good, the mill being 115 feet south of a large barn. The wheel has 30 curved sails, each 36 by 13 by 5.5 inches,[1] set at an angle of 30° (angle of weather) with the plane of the wheel. It is back-geared, 3 to 1, and held in the wind by a spring. The pump

[1] In this expression 36 is the length of the sail, 13 the width of sail at the outer end, and 5.5 the width of sail at the inner end.

also is of Woodmanse make, and is shown, in section, in fig. 5. The cylinder is 9.5 inches in diameter, the supply pipe 5.625 inches in diameter, the length of stroke 12 inches. The well is $3\frac{3}{4}$ feet by $3\frac{3}{4}$ feet to the water, a distance of 14 feet. At that point a 12-inch galvanized-iron pipe is put down 20 feet, forming a small open well. The lift at the time of test was $17\frac{3}{4}$ feet and the discharge per stroke $14\frac{1}{2}$ quarts. The mean barometric pressure was 26.98 inches, and the mean temperature 94° F. The cost of mill, tower, pump, and well was about $210. The results of the tests are as follows:

Results of tests of mill No. 2—12-foot Woodmanse Mogul.

[Load per stroke, 536.2 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horsepower.
12 miles	15.6	5.2	18.8	0.085
16 miles	48.0	16.0	58.0	0.260
20 miles	60.9	20.3	73.6	0.322
25 miles	69.9	23.3	84.5	0.379
30 miles	75.9	25.3	91.7	0.411

The curve shown in fig. 6 is for a moderately loaded 12-foot mill (536.2 foot-pounds per stroke). It starts at a wind velocity of 11

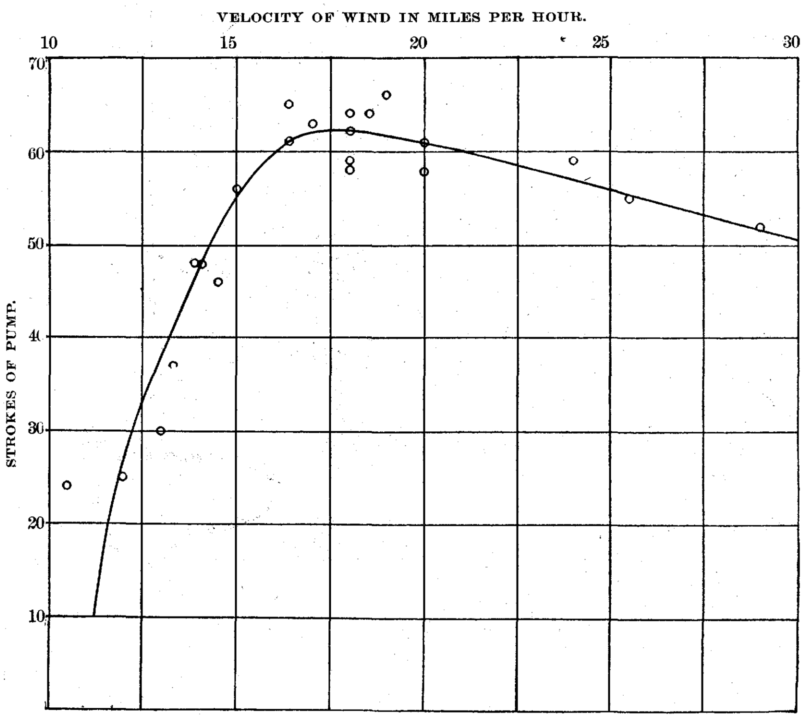
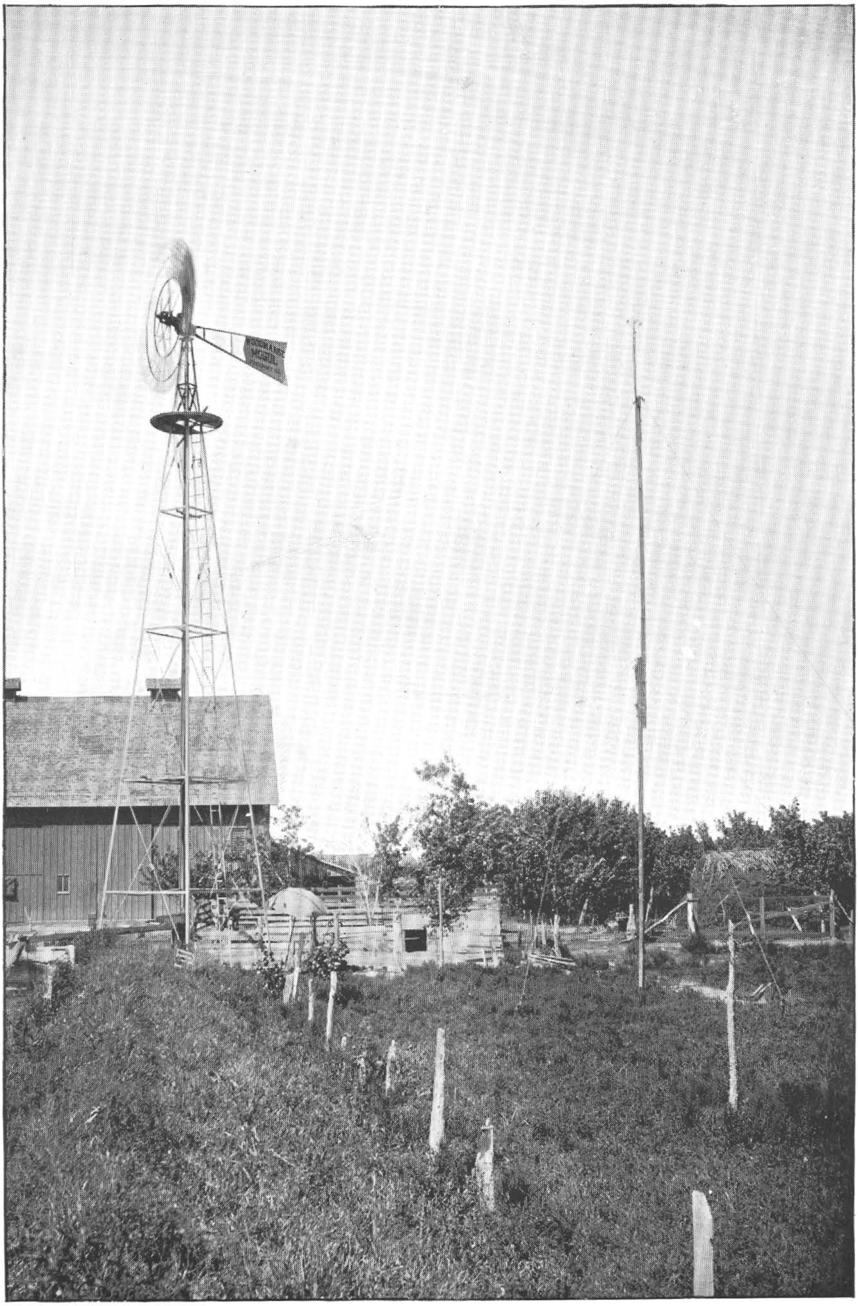


FIG. 6.—Diagram showing results with mill No. 2—12-foot Woodmanse Mogul.



VIEW OF MILL NO. 2 (12-FOOT WOODMANSE MOGUL) AND ANEMOMETER.

miles an hour. It ascends very rapidly, reaching a maximum at 18 miles an hour, and giving 60 strokes to the mile. The rest of the curve to 30 miles has a gentle slope. The number of strokes per minute increases from about 5 at 12 miles to about 25 at 30 miles an hour, and will continue to increase to probably 28 a minute in a 40-mile wind.

Mill No. 3.—This is a 12-foot Aermotor manufactured by the Aermotor Company, of Chicago, Illinois. Pl. IV shows the mill with its tower, pump, and pond, and fig. 7 shows its working parts. This mill had been in use about one year at the time of test, and all of the parts were in good working order. The tower is of wood, the axis of the wheel being 30 feet above the ground. The exposure is very good. The wheel has 18 curved sails, each 44 by 18¾ by 7¾ inches, set at an angle of 31° to the plane of the wheel. It is back-geared, 3⅓ to 1, and is held in the wind by a spring. The pump is of the Stone type, shown in figs. 8 and 9; the check valve is of the single-flap variety, the plunger valve of the double-flap variety. The cylinder is 9½ inches in diameter, the supply pipe 4 inches in diameter, and the discharge pipe 10 inches in outside diameter; the length of stroke is 12 inches and the discharge per stroke 14½ quarts. The well is 4 feet by 4 feet to a depth of 8 feet—nearly down to water. From that point to a depth of 18 feet it is 3 feet in diameter; and from there three pipes, 12 inches in diameter, extend down 5 feet farther. The lift at the time of test was 13¾ feet, the barometric pressure 27.2 inches, and the temperature 85° F. The water is pumped into a pond

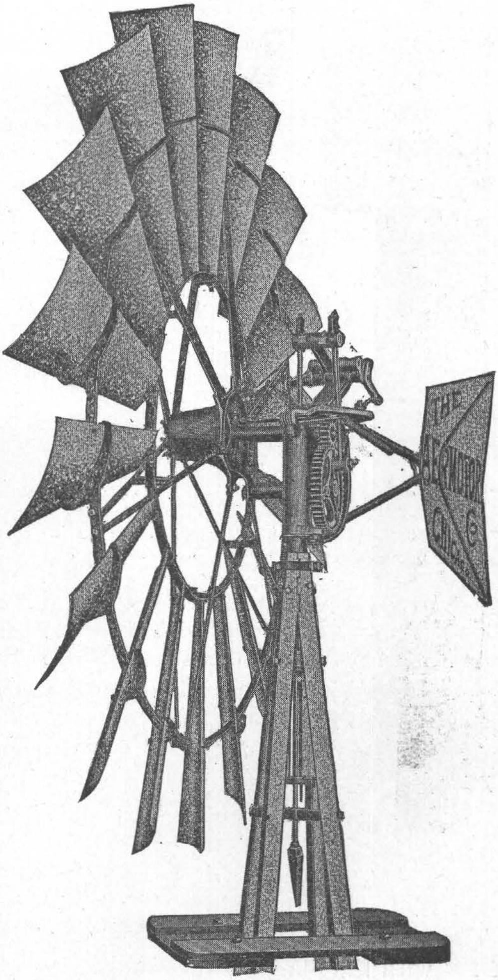


FIG. 7.—Working parts of Aermotor

80 feet by 75 feet, and a depth of 22 inches can be drawn off. The cost of the plant, including mill, tower, pump, and pond, was $145. The greatest number of strokes per minute is probably 27 or 28 in a 40-mile wind. In general appearance this curve is seen to resemble that of mill No. 2, but it is about 4 miles farther to the left, due to lighter load. The results of the tests are as follows:

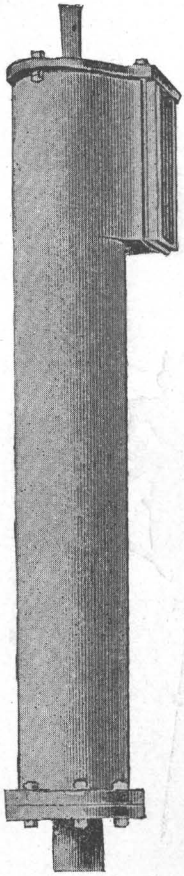


FIG. 8.—Stone pump.

Results of tests of mill No. 3—12-foot Aermotor.

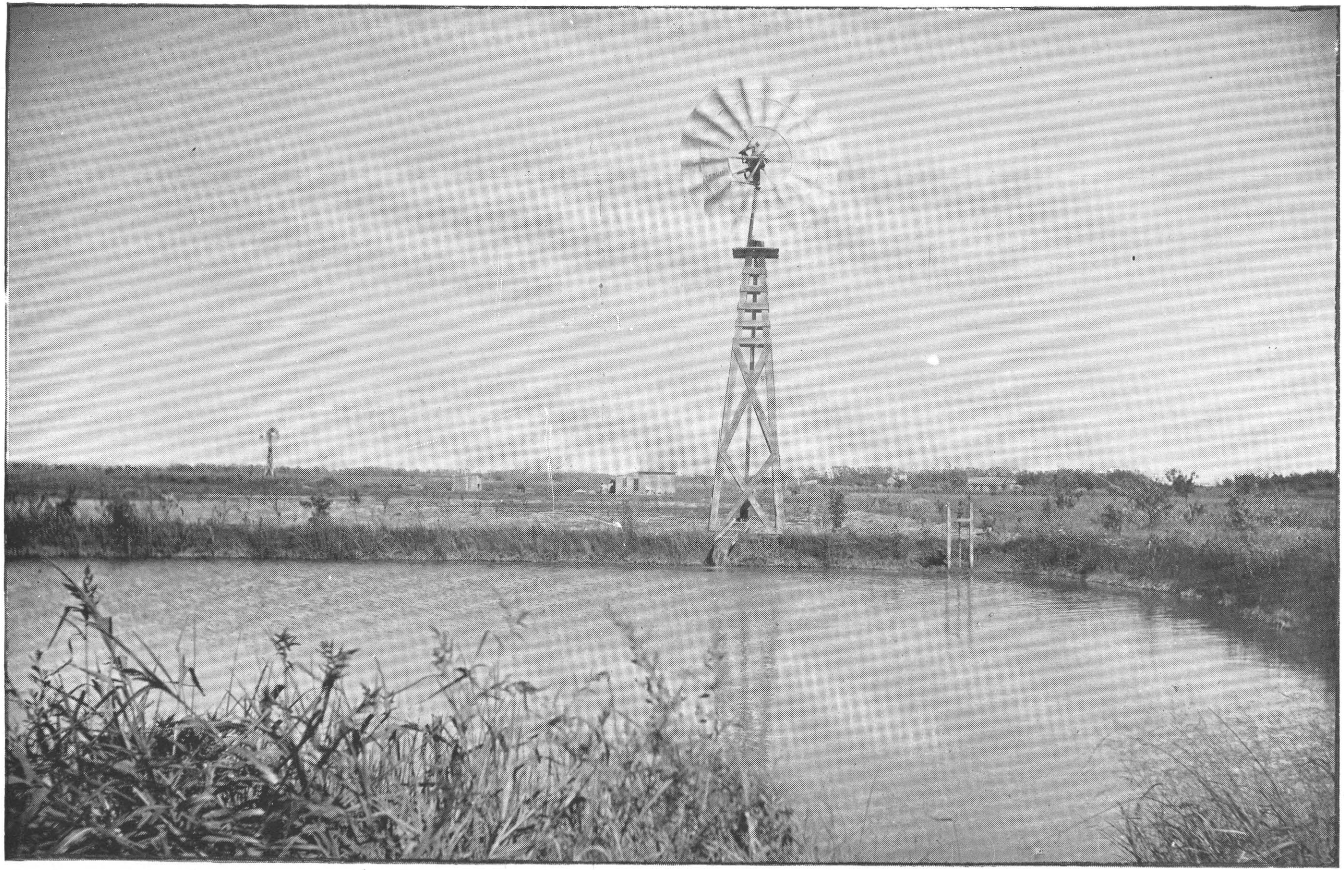
[Load per stroke, 415.3 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	17.7	5.3	19.3	0.067
12 miles	40.0	12.0	43.5	0.151
16 miles	54.7	16.4	59.5	0.207
20 miles	66.0	19.8	71.8	0.250
25 miles	77.0	23.1	83.6	0.291
30 miles	83.3	25.0	90.6	0.315

The curve shown in fig. 10 is for a rather lightly loaded mill (415.3 foot-pounds per stroke). It starts at a velocity of 6 to 7 miles an hour, ascends less rapidly than the one shown in fig. 6, attains a maximum at about 15 miles an hour, when the number of strokes per mile is 62, and then descends slowly, reaching 50 strokes at 30 miles. The number of strokes per minute increases from about 5 at 8 miles to 25 at 30 miles.

Mill No. 4.—This mill, shown in the foreground of Pl. V, is an 8-foot Ideal windmill manufactured by the Stover Manufacturing Company, of Freeport, Illinois. It had been in use about one year, and all of the parts were in good condition. The tower is of wood, the axis of the wheel being 48 feet above the ground.

The wheel has 15 sails, each $16\frac{1}{8}$ by 7 by 30 inches, set at an angle of 29° with the plane of the wheel. It is back-geared, $2\frac{1}{2}$ to 1, and is held in the wind by a spring. The pump is of the Stone make. The diameter of the discharge pipe is $5\frac{5}{8}$ inches, of the supply pipe 3 inches. The length of stroke is 8 inches. The plunger and check valves are of the single-flap variety. The well is $2\frac{3}{4}$ feet by $2\frac{3}{4}$ feet down nearly to water—a depth of $5\frac{1}{4}$ feet. The 3-inch supply pipe extends down to a depth of 14 feet, and on the end of it is a 3-inch well point 6 feet long. The lift may vary from $8\frac{1}{2}$ to 20 feet. It was probably about 12 feet at the time of tests. The discharge per stroke was 2 quarts. The mean barometric pressure was 27.19 inches, the mean tempera-



VIEW OF MILL NO. 3—12-FOOT AERMOTOR.

ture 83° F. The water is pumped into a pond 115 feet by 31 feet and 3 feet deep. The cost of the plant, including mill, pump, well, and pond, was $80. The results of the tests are as follows:

Results of tests of mill No. 4—8-foot Ideal.

[Load per stroke, 50 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	25.5	10.2	5.1	0.015
16 miles	48.2	19.3	9.6	0.029
20 miles	63.2	25.3	12.6	0.038
25 miles	70.3	28.1	14.1	0.043
30 miles	62.5	25.0	12.5	0.038

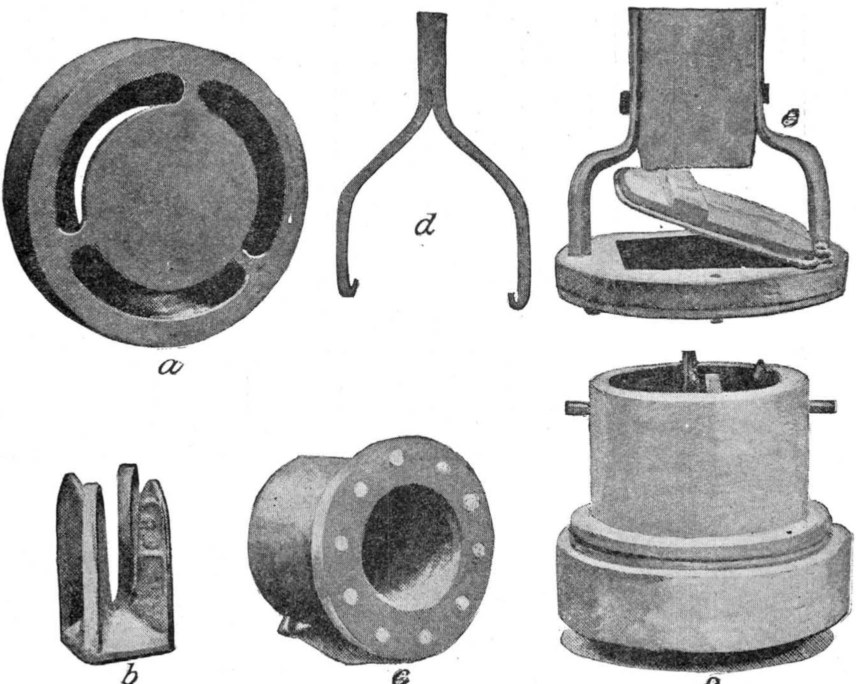


FIG. 9.—Details of Stone pump: *a*, Lower valve seat; *b*, ring guide to lower valve; *c*, lower or check valve; *d*, hook for removing lower valve; *e*, plunger and valve; *f* is *a*, *b*, and *c* combined.

The curve shown in fig. 11, although for a rather lightly loaded mill—50 foot-pounds per stroke—shows that the mill starts in a 10-mile to an 11-mile wind. The maximum is reached at 19 miles, with a speed of 78 strokes. The right side of the curve is quite steep, a characteristic of this make of mill. Mill No. 18 is the same size and make as this mill, and yet with a load of 89.2 foot-pounds it starts in a 7-mile to an 8-mile wind, reaching a maximum at about 13 miles, at

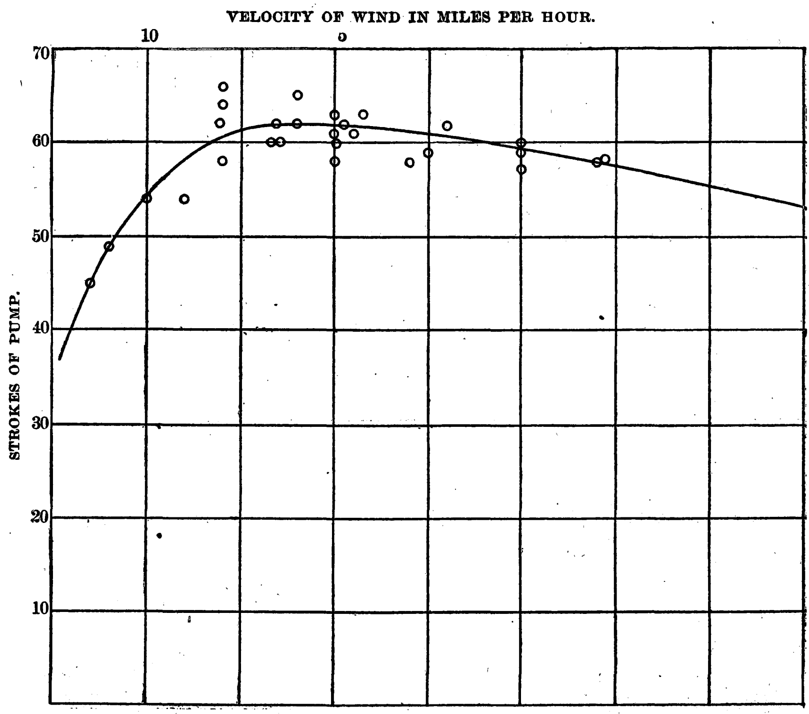


FIG. 10.—Diagram showing results with mill No. 3—12-foot Aermotor.

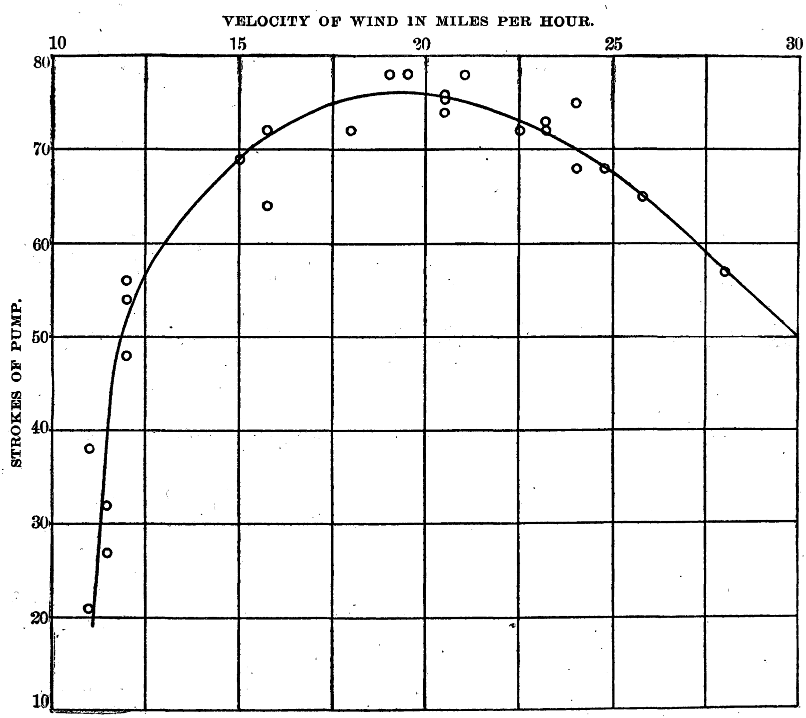
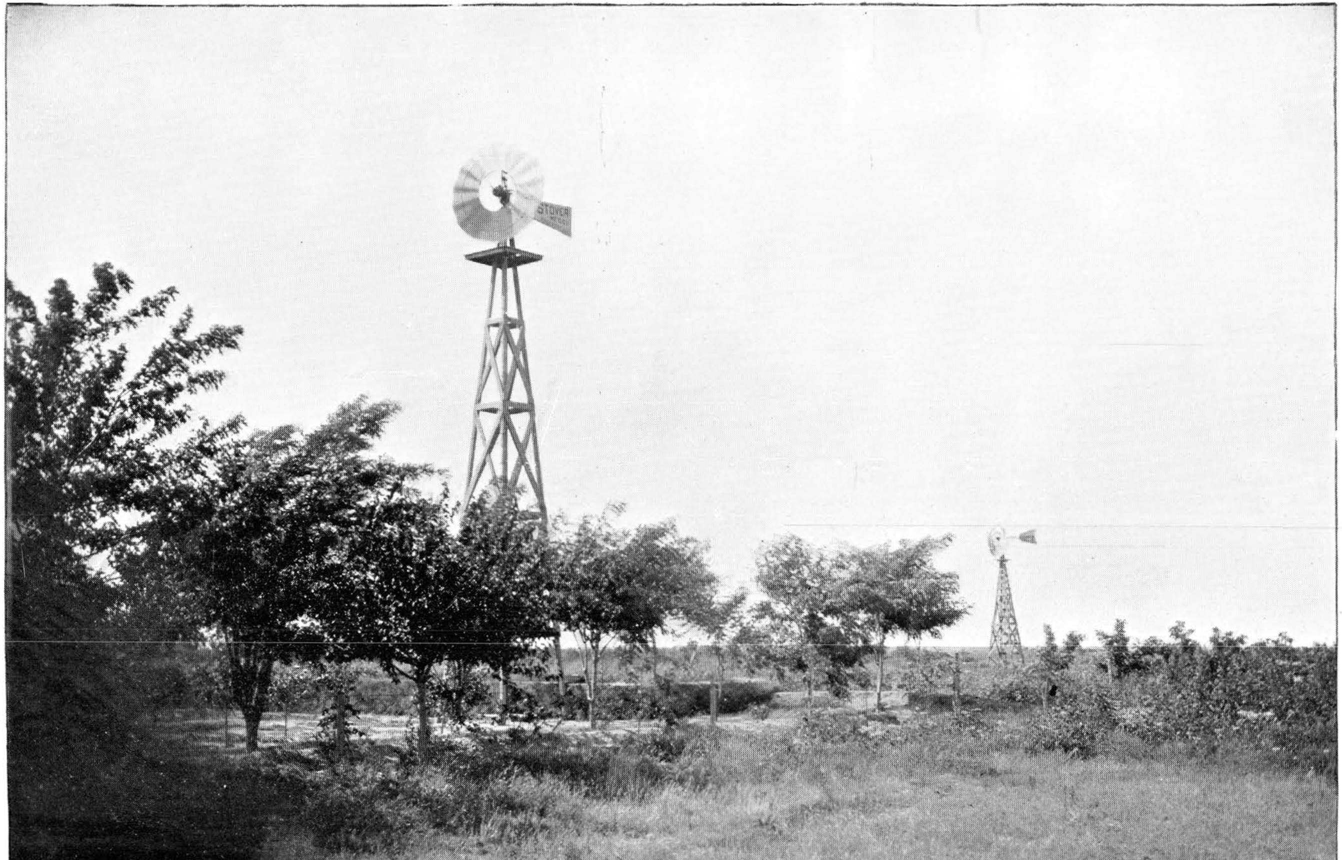


FIG. 11.—Diagram showing results with mill No. 4—8-foot Ideal.



VIEW OF MILLS NO. 4 (8-FOOT IDEAL) AND NO. 5 (8-FOOT AERMOTOR).

a speed of 104 strokes per mile. A second test, when the spring that holds the wind wheel in the wind was tightened somewhat, gave the maximum at a velocity of about 15 miles, with a pump speed of about 114 strokes. The difference appeared to be due to the difference in pumps and wells. The rapid fall in the curve to the right of the highest point is due to the easy governing of the mill.

Mill No. 5.—This mill, shown in the background of Pl. V, is an 8-foot Aermotor manufactured by the Aermotor Company, of Chicago, Illinois. The tower is of wood, and is 28.5 feet high to the axis of wheel. The exposure is good, and all of the parts were in good working order at the time of tests, the plant having been in use about one year. The wheel has 18 curved sails, each 30 by $12\frac{1}{2}$ by $5\frac{1}{2}$ inches, making an angle of $29\frac{1}{2}°$ with the plane of the wheel. It is back-geared, $3\frac{1}{3}$ to 1. The pump is of the Stone make. The discharge pipe is 6 inches in diameter, the supply pipe 3 inches in diameter. The valves (check and plunger) are of the single-flap variety. The length of stroke is 8 inches. The well is 4 feet by 4 feet to water, a depth of 10.5 feet. A 12-inch wooden curb extends 12 feet farther into the sand and gravel. The discharge per stroke was $3\frac{1}{2}$ quarts, and the lift 13 feet. The cost of plant, including pond, was $80.

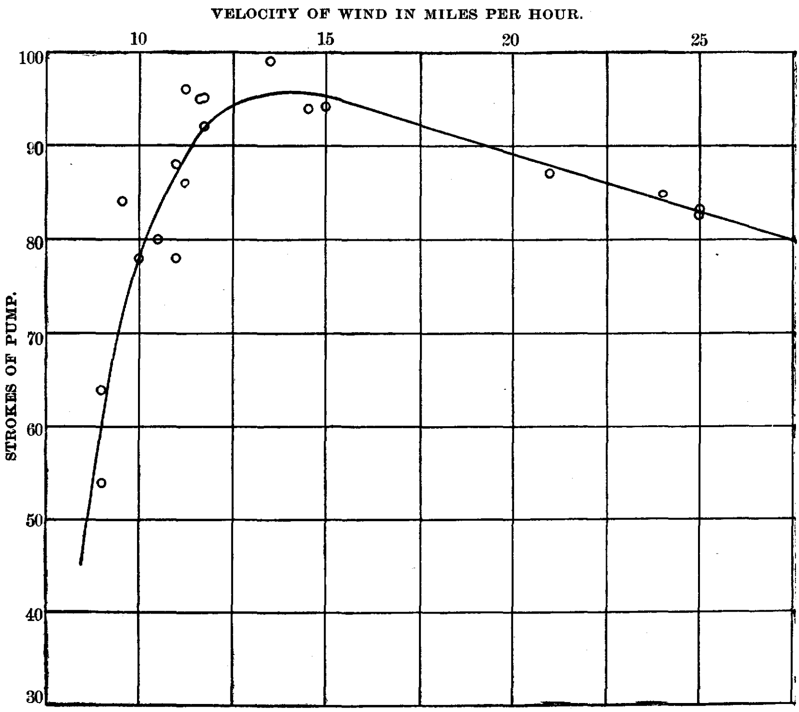


FIG. 12.—Diagram showing results with mill No. 5—8-foot Aermotor.

The results of the tests of mill No. 5 are as follows:

Results of tests of mill No. 5—8-foot Aermotor.

[Load per stroke, 94.9 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	62.0	18.6	16.3	0.053
16 miles	83.7	25.1	22.0	0.072
20 miles	99.3	29.8	26.1	0.086
25 miles	115.3	34.6	30.3	0.099
30 miles	128.3	38.5	33.7	0.111

This 8-foot mill, with a load of 95 foot-pounds, is seen to start in an 8-mile to a 9-mile wind (fig. 12), reaching a maximum at 13 to 15 miles, with 95 strokes per mile. At 30 miles an hour it is making 77 strokes per mile, or 39 strokes per minute. This curve indicates a rather heavily loaded mill.

Mill No. 6.—This mill, shown in the background of Pl. IV, is an 8-foot Gem, manufactured by the United States Wind Engine and Pump Company, of Kansas City, Missouri. The working parts of the mill are shown in Pl. VI. The exposure was good and all of the parts were in good working order, the mill having been in use only about one year at the time of tests. The wheel has 24 curved sails, each $30\frac{1}{2}$ by 10 by $4\frac{1}{2}$ inches, set at an angle of 35° with the plane of the wheel. It is back-geared, 3 to 1. The wheel is held in the wind by means of a weight. The pump is of the Stone make. The discharge pipe is 6 inches in diameter, the supply pipe 4 inches in diameter. The length of stroke is 8 inches. The well is open to the water—a depth of $6\frac{1}{2}$ feet. The supply pipe is on a well point, the end of which is 16 feet below the surface of the ground. The lift was $9\frac{7}{12}$ feet and the discharge per stroke 3.9 quarts. The tower is of wood, and is 24 feet high to the axis of the wheel. The mean barometric pressure was 27.02 inches, the mean temperature 85° F. The plunger valve is of the double-flap variety, and the check valve of the single-flap variety. The results of the tests are as follows:

Results of tests of mill No. 6—8-foot Gem.

[Load per stroke, 77.6 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	37.2	12.4	12.1	0.029
16 miles	53.7	17.9	17.5	0.042
20 miles	66.0	22.0	21.5	0.051
25 miles	76.2	25.4	24.7	0.059
30 miles	85.5	28.5	27.8	0.065

Comparing the number of strokes per minute of mills Nos. 4, 5, and 6, it is seen that although No. 5 is carrying a much heavier load than either of the other mills, it makes more strokes and does much more work at all velocities.

Mill No. 7.—This is a 12-foot Aermotor similar to mill No. 3. The tower is of steel, having a height of 31 feet to the axis of the wheel. The exposure was good and all of the parts were in good working order, the plant having been in use less than one year when tests were made. The pump is of the Stone make and is like that of mill No. 3, except that the check valve is of the solid-lift variety. The lift was 15½ feet and the discharge 14.3 quarts per stroke. The water is pumped into a pond 135 feet by 50 feet by 2½ feet.

Comparing the results of the tests of this mill with those of mill No. 3, it is seen that the latter is somewhat more heavily loaded than the former and makes a few less strokes per minute, but that its horsepower is a little greater. The effect of the larger load is shown.

The results of the tests of mill No. 7 are as follows:

Results of tests of mill No. 7—12-foot Aermotor.

[Load per stroke, 461.9 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horsepower.
12 miles	38.0	11.4	40.7	0.160
16 miles	52.7	15.8	56.5	0.221
20 miles	63.3	19.0	67.9	0.266
25 miles	73.7	22.1	79.0	0.309
30 miles	78.3	23.5	84.0	0.329

Mill No. 8.—This is a 10-foot Star wooden mill, manufactured by Bradley, Wheeler & Company, of Kansas City, Missouri. The tower is of wood, and the axis of the wheel 35½ feet above the ground. The water is pumped into an elevated tank 20 feet above the surface of the ground and is used for irrigation. The wheel has 60 plane sails, each 37 by 5 by 2¾ inches, set at an angle of 33° to the plane of the wheel. It is held in the wind by means of a weight. It is not back-geared, a stroke of the pump being made to each revolution of the wheel. The supply pipe is 2 inches in diameter and terminates in a well point, the end of which is 18 feet below the surface of the ground. The discharge pipe is 1¼ inches in diameter. The cylinder is 3 inches in diameter, the length of stroke 5 inches. The lift may vary between 28½ and 37 feet. It was estimated to be about 30 feet at the time of measurement. The discharge per stroke was 0.24 quart. The cylinder leaked some at the time of tests. After a new cylinder was put in the discharge per stroke was increased to 0.40 quart. The mean barometric pressure was 27.04 inches, the mean temperature 78° F. The results of the tests are as follows:

Results of tests of mill No. 8—10-foot Star wooden mill.

[Load per stroke, 15 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	28.0	28.0	1.7	0.013
12 miles	30.0	30.0	1.8	0.014

These results show the effect of the very light load and the readiness with which the wind wheel turns out of the wind. It makes 28 strokes per minute in an 8-mile wind and less than that in a 16-mile or higher wind.

Mill No. 9.—This is a 16-foot Aermotor. The tower is of steel, and the axis of the wheel is 30 feet above the ground. The wheel has 18

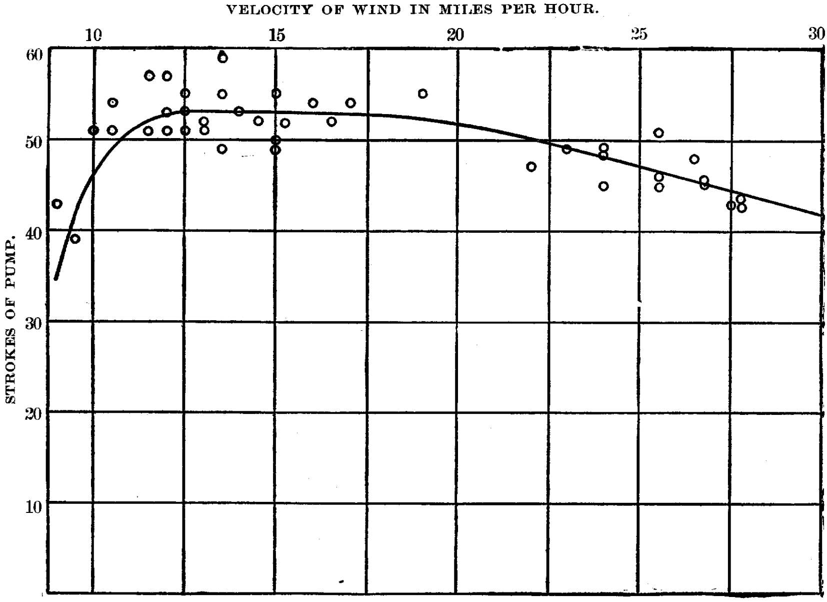


FIG. 13.—Diagram showing results with mill No. 9—16-foot Aermotor.

curved sails, each 59 by 25¾ by 10½ inches, set at an angle of 30° with the plane of the wheel. It is back-geared, 3 to 1. The discharge pipe is 12 inches in diameter, the supply pipe 6 inches in diameter, the cylinder 8 inches in diameter. The stroke is 16 inches. The well is 4 feet by 6 feet to a depth of 23 feet, 2 feet by 2 feet for the next 8 feet, and 18 inches in diameter for the next 14 feet. The water was 39½ feet below the surface of the ground. The lift was 44¼ feet and the discharge per stroke 11 quarts. The check valve is of the single-flap variety and the plunger valve of the double-flap variety. The mean barometric pressure was 27.04 inches, and the mean temperature 93° F. This plant had been in use about three years. The results of the tests are as follows:

Results of tests of mill No. 9—16-foot Aermotor.

[Load per stroke, 1,013 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	31.8	10.6	29.1	0.325
16 miles	42.3	14.1	38.8	0.433
20 miles	51.6	17.2	47.3	0.548
25 miles	58.8	19.6	53.9	0.601
30 miles	63.0	21.0	57.7	0.644

The curve shown in fig. 13 starts at a wind velocity of 8 to 9 miles, and reaches a maximum at 13 miles, with a speed of 53 strokes per mile. From that point to a velocity of about 19 miles the curve is nearly horizontal; after 19 miles it descends slowly to 32 miles, with 38 strokes per mile. The speed increases from 11 strokes per minute at 12 miles to 21 strokes per minute at 30 miles an hour.

Mill No. 10.—This is an 8-foot Ideal. The tower is of wood, the axis of the wheel being 30 feet above the ground. The wheel has 15 curved sails, each 31 by 19 by 7 inches, set at an angle of 29½° with the plane of the wheel. It is back-geared, 2½ to 1. The supply pipe is 1½ inches in diameter, the cylinder 2½ inches in diameter. The pump is a common hand pump, with lift valve of the flap form and plunger of the lift variety. The valves leak some, as the discharge is greater when the pump is working rapidly than when it is working slowly. The supply pipe is on a well point 2 feet long and 1½ inches in diameter, the lower end of which is 50 feet below the surface of the ground. The lift was 33 feet and the discharge per stroke one-third of a quart when pumping quite rapidly. The mean barometric pressure was 26.94 inches, the mean temperature 97° F. The results of the tests are as follows:

Results of tests of mill No. 10—8-foot Ideal.

[Load per stroke, 22.8 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	35.2	14.1	1.2	0.010
12 miles	62.5	25.0	2.1	0.017
16 miles	83.2	33.3	2.8	0.023
20 miles				0.032

Mill No. 11.—This is a 12-foot Ideal, the working parts of which are shown in fig. 14. The tower is of steel, the axis of the wheel being 30 feet above the ground. The exposure was good, and all of the

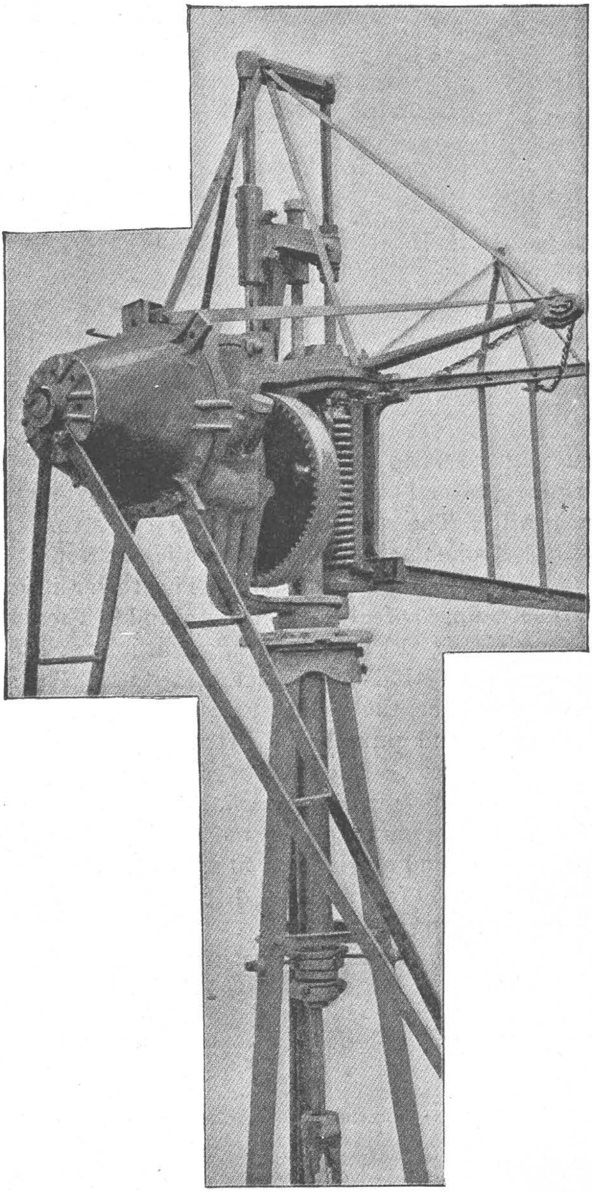


FIG. 14.—Working parts of mill No. 11—12-foot Ideal.

parts were in good working order when mill was tested. The wheel has 21 curved sails, each 31 by 19 by 7 inches, set at an angle of $29\frac{1}{2}°$ to the plane of the wheel. It is back-geared, $2\frac{1}{2}$ to 1, and the wheel is held in the wind by a spring. The discharge pipe is 8 inches in diameter, and the length of stroke is 12 inches. The supply pipe consists of two 3-inch pipes 14 feet long, each terminating in a 3-inch well point 3 feet long. The valves (check and plunger) are of the single-flap variety. The water was 39 feet below the surface of the ground. The lift, as nearly as could be ascertained at the time of measurement, was 45 feet, the discharge per stroke 9 quarts. The water is pumped into a pond 60 feet by 40 feet by 6 feet. This plant had been in use about three years. The mean barometric pressure was 26.91 inches, the mean temperature 91° F. The results of the tests are as follows:

Results of tests of mill No. 11—12-foot Ideal.

[Load per stroke, 843.7 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	12.0	4.8	10.8	0.123
16 miles	31.7	12.7	28.6	0.325
20 miles	47.0	18.8	42.3	0.481
25 miles	58.2	23.3	52.5	0.600
30 miles	62.5	25.0	56.2	0.639

Mills Nos. 9 and 11 pump water into the same pond from the same depth. It will be seen from these results that for wind velocities of

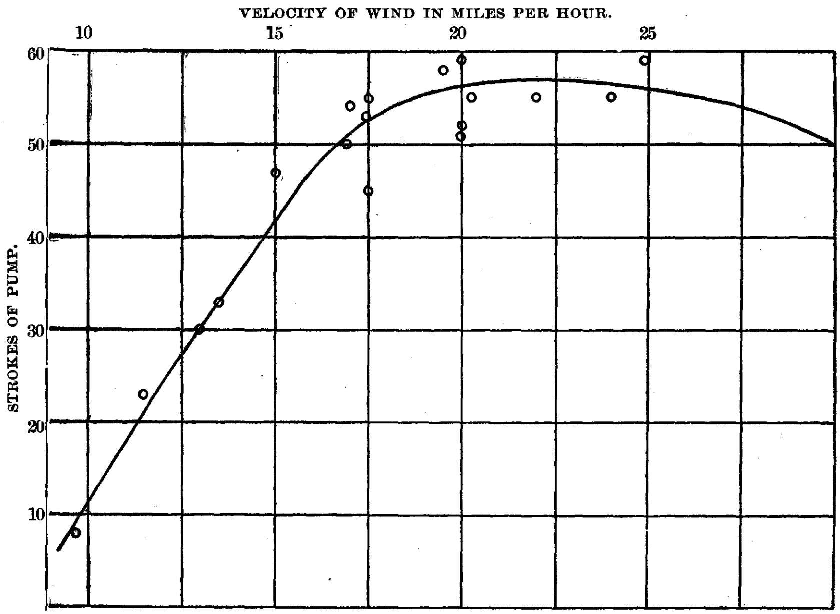


FIG. 15.—Diagram showing results with mill No. 11—12-foot Ideal.

20 miles or more the 12-foot mill is pumping nearly as much water as the 16-foot mill; for velocities of 12 miles or less the 16-foot mill is pumping much more water than the 12-foot mill.

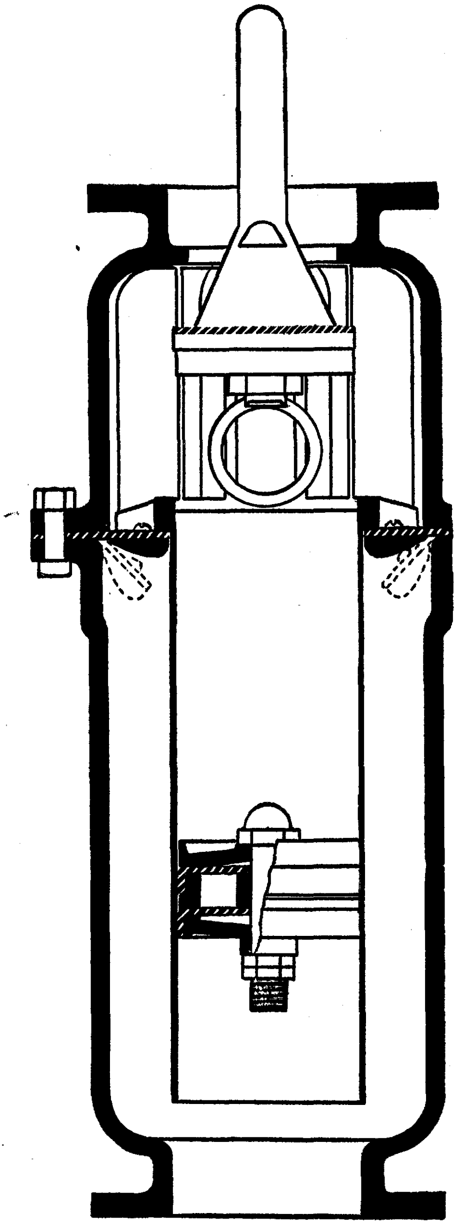
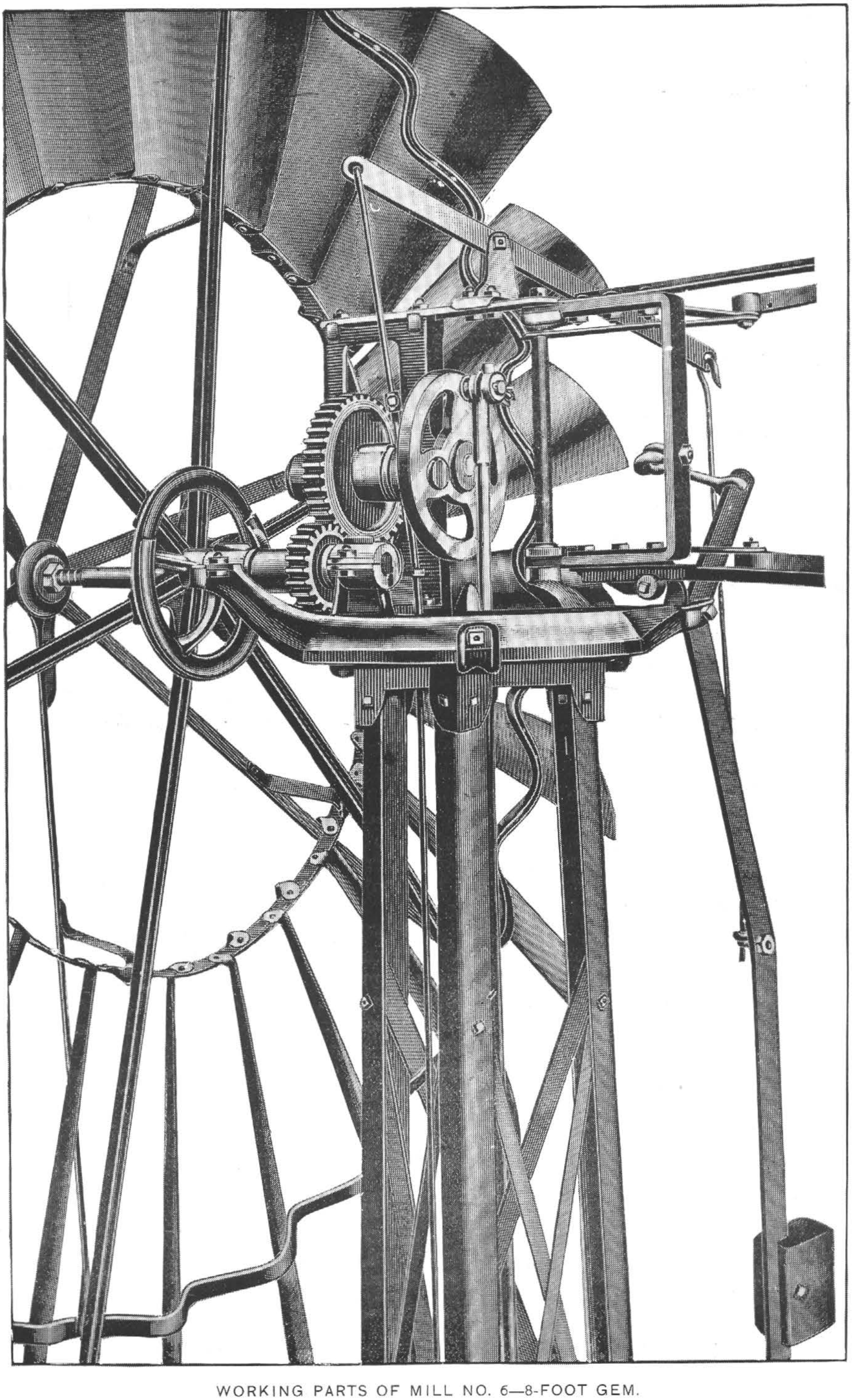


FIG. 16.—Working parts of Frizell cylinder.

This curve (fig. 15) is for a heavily loaded (843.7 foot-pounds per stroke) 12-foot mill. It starts with a velocity of about 10 miles an hour, and reaches a maximum at about 23 miles, with a speed of 57 strokes per mile. At 30 miles it is making 51 strokes per mile. The maximum point of this curve is much farther to the right than that of any other curve. The number of strokes increases from 5 per minute at 12 miles to 25 per minute at 30 miles.

Mill No. 12.—This is a 14-foot Ideal, shown in Pl. VII. The tower is of steel and is 30 feet high to the axis of the wheel. The wheel has 24 curved sails, each $48\frac{3}{4}$ by $17\frac{1}{2}$ by 8 inches, set at an angle of 30° with the plane of the wheel. It is back-geared, $2\frac{1}{2}$ to 1. The pump is of the Frizell make (shown in fig. 16). The discharge pipe is 10 inches in diameter, the cylinder $9\frac{1}{2}$ inches in diameter, the supply pipe 6 inches in diameter, terminating in a well point 10 feet long and 6 inches in diameter, the lower end of which is 32 feet below the surface of the ground. The lift, as nearly as could be estimated, was 11 feet, the discharge per stroke 11.6 quarts. The mean barometric pressure was 27.04 inches, the mean temperature 81° F. The water is pumped into a reservoir 100 feet by 100 feet by 3 feet deep. The pump had been in use about one year. The results of the tests are as follows:



WORKING PARTS OF MILL NO. 6—8-FOOT GEM.

Results of tests of mill No. 12—14-foot Ideal.

[Load per stroke, 263.5 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	7.7	3.1	8.9	0.025
12 miles	27.2	10.9	30.1	0.087
16 miles	39.3	15.7	45.1	0.125
20 miles	48.0	19.2	55.2	0.153
25 miles	53.7	21.5	61.8	0.173

This curve (fig. 17) is for a very lightly loaded (263.5 foot-pounds) 14-foot mill. This load is only 31 per cent of that of the 12-foot mill, No. 11. The curve starts in a 7-mile to an 8-mile wind, and reaches a maximum at 15 miles, with a speed of 58 strokes per mile of wind. At 30 miles the speed is 47 strokes. Although this is a very lightly

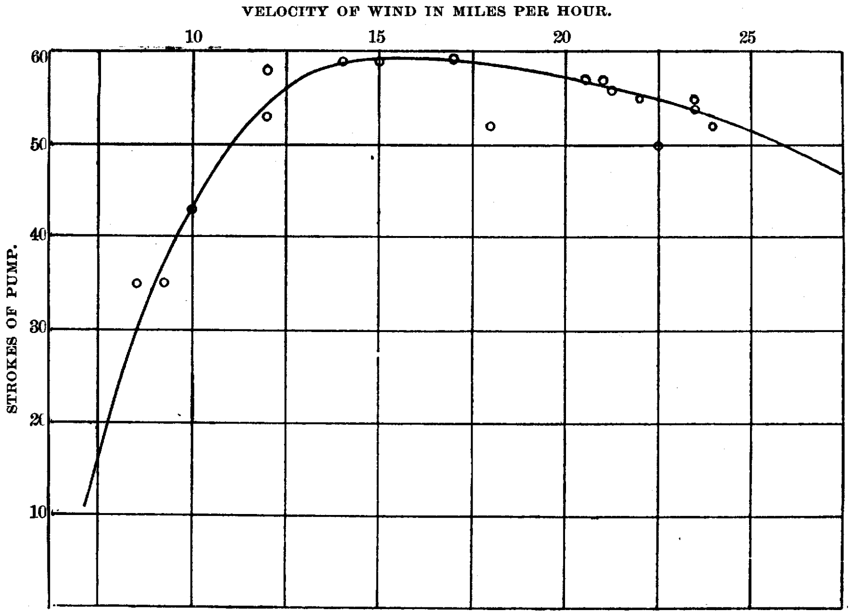


FIG. 17.—Diagram showing results with mill No. 12—14-foot Ideal.

loaded mill it does not make many strokes per minute. In fact, although it is not as heavily loaded as the 12-foot mill, No. 3, it does not make as many strokes per minute as the latter mill, and it is producing much less power than mill No. 3.

Mill No. 13.—This is a 12-foot Aermotor (shown in Pl. VIII). The tower is of wood, with the axis of the wheel 25 feet above the ground. The exposure was good and the plant in excellent condition, having been in use about one year at the time of tests. The wheel is the same as that of No. 3. The pump is of the Stone make. The discharge pipe is 10 inches in diameter, the supply pipe 5 inches in diameter, on a well point 10 feet long, the lower end of which is 17 feet below the surface of the ground. The length of stroke is 12 inches. The plunger valve is of the double-flap type, and the check valve of the single-flap type. The discharge per stroke at the time of test was 14.4 quarts and the lift about 11 feet. The mean barometric pressure was 27.09 inches, the mean temperature 91° F. The results of the tests are as follows:

Results of tests of mill No. 13—12-foot Aermotor.

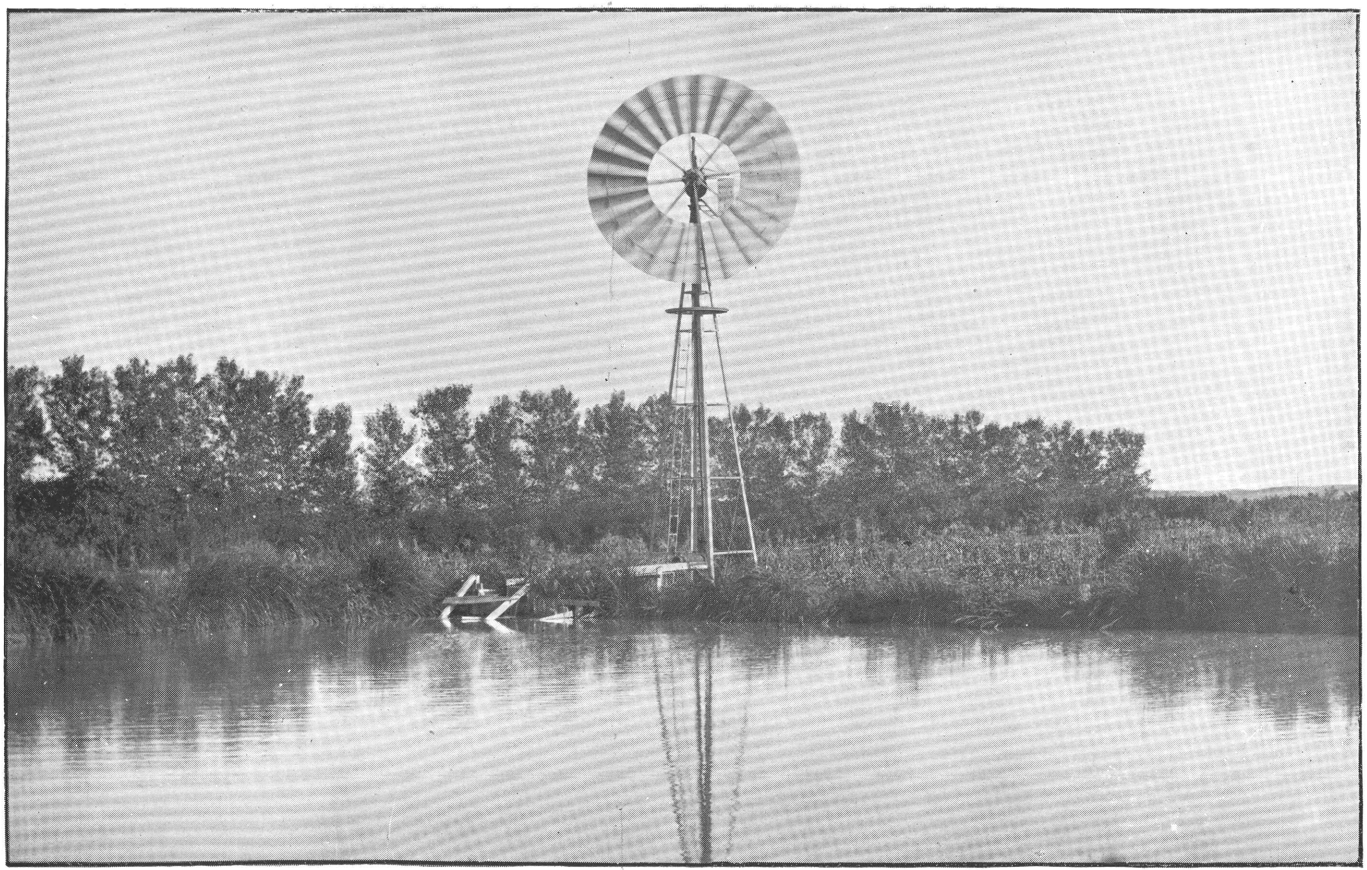
[Load per stroke, 330 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	36.7	11.0	39.6	0.110
16 miles	57.0	17.1	61.6	0.171
20 miles	70.0	21.0	75.6	0.210
25 miles	82.0	24.6	88.6	0.247
30 miles	91.7	27.5	99.0	0.275

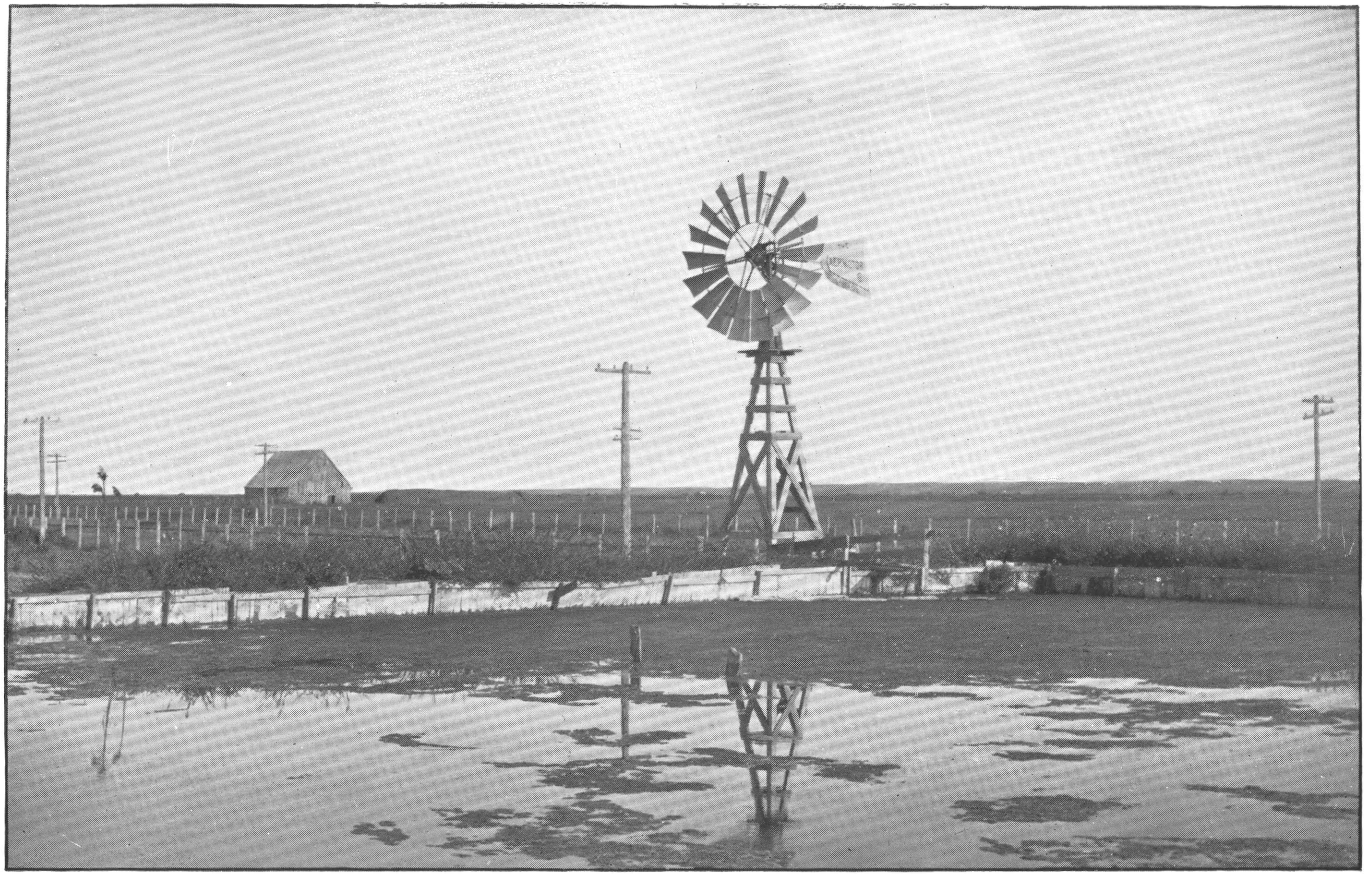
The important difference between this plant and No. 3 is that the latter has a 4-inch supply pipe and an open well, while the former has a 5-inch supply pipe on a well point. The useful load per stroke of mill No. 13 is 20 per cent less than that of mill No. 3, and the number of strokes per minute of No. 13 is slightly greater than that of No. 3. It appears that the well point offers some resistance, but how much can not be said from this data.

Mill No. 14.—This is a 12-foot Gem, like the one shown in Pl. IX, on a 60-foot steel tower. The pump is of the Gause make. The cylinder is 8 inches in diameter, the length of stroke 9 inches. The supply is from a 12-inch pipe in an open well. The discharge per stroke was 9¾ quarts and the lift 15½ feet. The wind velocity was not measured.

Mill No. 15.—This is a 10-foot Gem similar to that shown in Pl. IX. The tower is of wood, the axis of the wheel being 34 feet above the ground. The mill was in good working order, but the exposure was not good, on account of trees. The wheel has 24 sails, each 36 by 11 by 4¾ inches, set at an angle of 35° with the plane of the wheel. It is back-geared, 3 to 1. The pump is of the Stone make. The discharge pipe is 8 inches in diameter. The supply pipe is on a 3-inch well point 8 feet long, the lower end of which is 21½ feet below the surface of the ground. The plunger valve is of the single-flap form. Depth to water is 10 feet. The discharge per stroke was 7 quarts, the lift about 15 feet. The mean barometric pressure was 27.05 inches, the mean temperature 84° F.



VIEW OF MILL NO. 12—14-FOOT IDEAL.



VIEW OF MILL NO. 13—12-FOOT AERMOTOR.

The results of the tests are as follows:

Results of tests of mill No. 15—10-foot Gem.

[Load per stroke, 219 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	23.4	7.8	13.6	0.053
16 miles	35.7	11.9	21.0	0.082
20 miles	44.1	14.7	25.7	0.101
25 miles	43.8	14.6	25.5	0.099

This mill revolves very slowly, indicating a heavy load. Its useful horsepower, however, is little greater than that of mill No. 5.

Mill No. 16.—This is a 10-foot Halliday, pumping water into the same pond as No. 15. It is similar to the mill shown in fig. 20. The tower is of wood, the axis of the wheel being 28 feet above the ground. The wheel has 78 sails, each 36¼ by 4 by 2¼ inches, set at an angle of 35.5° to the plane of the wheel. It is not back-geared. The pump is of the Gause make, with a discharge pipe 6 inches in diameter and a supply pipe 4 inches in diameter. There is a 6-inch galvanized-iron pipe, forming an open well, extending 15 feet into the water. The depth to water was 11 feet, the lift 16 feet, and the discharge per stroke 3 quarts. The mean barometeric pressure was 27.02 inches, the mean temperature 94° F. The results of tests are as follows:

Results of tests of mill No. 16—10-foot wooden Halliday.

[Load per stroke, 100 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	4.0	4.0	3.0	0.012
12 miles	22.6	22.6	16.9	0.067
16 miles	33.9	33.9	25.4	0.103
20 miles	42.7	42.7	32.0	0.130
25 miles	52.5	52.5	39.3	0.159

This 10-foot wooden mill is seen to be doing more useful work than the 10-foot steel Gem, No. 15. Usually, however, the direct-stroke wooden mills do less work than the back-geared steel mills of the same size.

Mill No. 17.—This is a 12-foot improved Gem on a 30-foot steel tower. The wheel has 32 curved sails, each 42 by 11½ by 4¾ inches, set at an angle of 37° with the plane of the wheel. It is back-geared, 2 to 1. The pump is of the Gause type, with an 8-inch discharge pipe, a 4-inch supply pipe, 12 inches stroke, and an open well formed of a 12-inch wooden casing. The depth to water was 17¼ feet, and the discharge per stroke 8¾ quarts. The mean barometric pressure was 27.05 inches, the mean temperature 93° F. The results of the tests are as follows:

Results of tests of mill No. 17—12-foot improved Gem.

[Load per stroke, 385 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	12.0	6.0	12.7	0.070
16 miles	25.6	12.8	27.2	0.149
20 miles	34.6	17.3	36.8	0.202

This mill, although nearly new, does not work well. It is out of plumb. Only a few measurements of the number of strokes per mile of wind were made.

Mill No. 18.—This is an 8-foot Ideal on a 36-foot wooden tower. The exposure was good and the parts in good working order. The wheel is like that of mill No. 4. The pump is of the Stone make, with a 6-inch discharge pipe. There is no supply pipe, the cylinder being under water, with 3 inches opening to it from below. The check valve is of the lift variety, the plunger valve of the single-flap variety. The well is dug to a depth of 8 feet. It is 4⅓ feet in diameter. In the bottom a 10-inch galvanized-iron pipe extends down several feet. It was 11 feet to water. The lift was 14⅓ feet and the discharge per stroke 2.92 quarts. The mean barometric pressure was 27.01 inches, the mean temperature 83° F. The cost of the plant, including pond, was $125. The results of the tests are as follows:

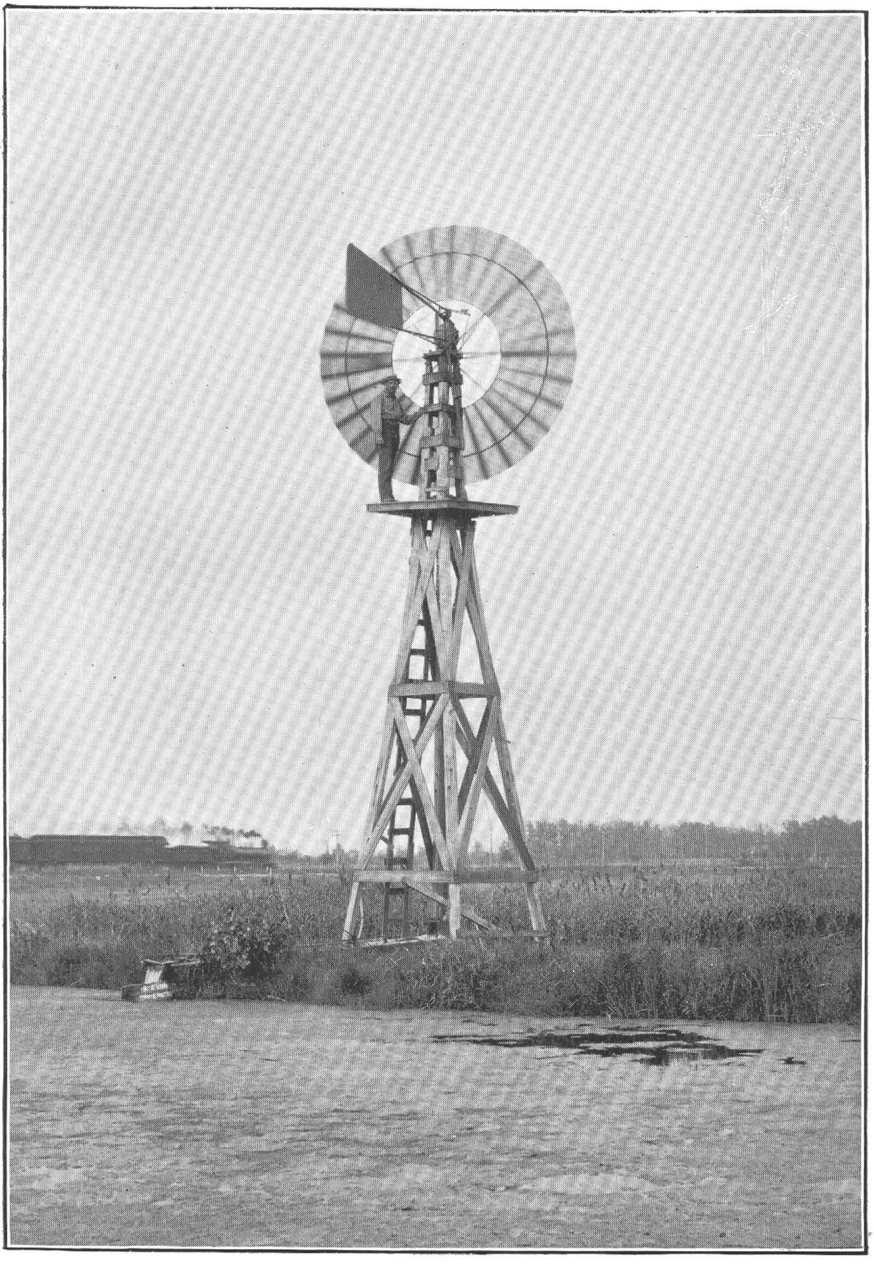
Results of tests of mill No. 18—8-foot Ideal.

[Load per stroke, 89.2 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	20.0	8.0	5.8	0.022
12 miles	50.5	20.2	14.6	0.054
16 miles	65.2	26.1	18.9	0.070
20 miles	70.0	28.0	20.3	0.076
25 miles	68.7	27.5	19.9	0.074

After the spring which holds the wind wheel of this mill in the wind was tightened, the number of strokes per mile of wind was increased from 98 to 114 in a 16-mile wind, from 84 to 102 in a 20-mile wind, and from 66 to 79 in a 25-mile wind.

Mill No. 19.—This is a 12-foot Gem (shown in Pl. IX) on a 30-foot wooden tower. The exposure was good and the mill in good working order. The wheel is like that of mill No. 17. The pump is of the Stone make, with a 10-inch discharge pipe and a 4-inch supply



VIEW OF MILL NO. 19—12-FOOT GEM.

pipe. The length of the stroke is 10 inches. The supply pipe is on a 4-inch well point 9 feet long, the end of which is 23 feet below the surface of the ground. The check valve is of the lift type and the plunger valve of the single-flap type. The lift was about 18 feet and the discharge per stroke 12 quarts. The mean barometric pressure was 27.13 inches, the mean temperature 70° F. The water is pumped into a reservoir 120 feet by 60 feet. The results of the tests are as follows:

Results of tests of mill No. 19—12-foot Gem.

[Load per stroke, 450 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Stroke of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	12.4	6.2	18.6	0.085
16 miles	23.8	11.9	35.7	0.162
20 miles	29.4	14.7	44.1	0.201
25 miles	32.0	16.0	48.0	0.219

This curve (fig. 18) shows that a 9-mile wind is necessary to start this mill, and that the greatest number of strokes per mile of wind

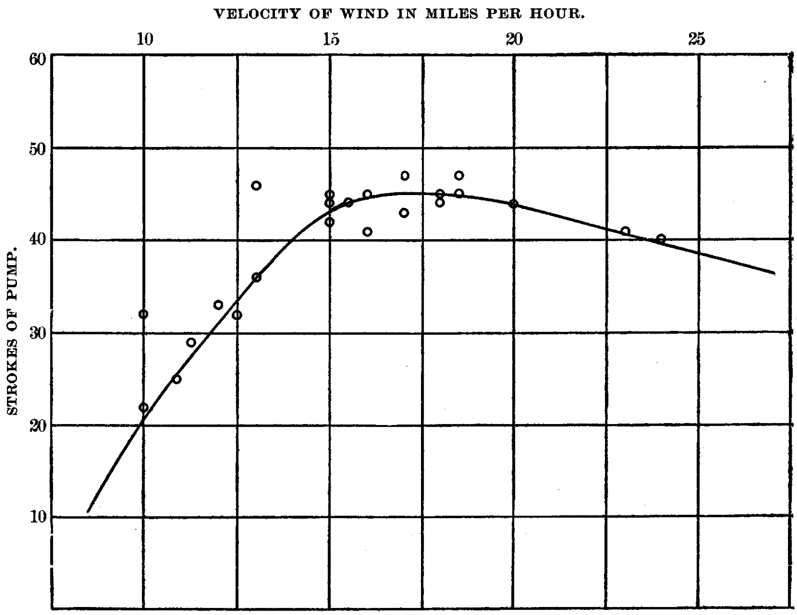


FIG. 18.—Diagram showing results with mill No. 19—12-foot Gem.

is 45—about 25 per cent less than most 12-foot steel back-geared mills, being at the rate of 6 strokes at 12 miles and 16 strokes at 25 miles an hour. The load of this mill is somewhat greater than that of No. 3, and its power should be equal or greater, but it is seen to be much less.

Mill No. 20.—This is a 15½-foot Jumbo (shown in Pl. X, *A*). Its axis is a steel shaft 8 feet above the ground. It has 6 sails, each 9½ by 3½ feet, with an outer radius of 7¾ feet and an inner radius of 4½ feet. This mill operates two pumps, one at each end of the axis, each pump having a 6-inch cylinder, a 3-inch discharge pipe, and a 3-inch supply pipe on a well point 5 feet long. The discharge per stroke of the two pumps was 10 quarts, the lift about 14 feet. The mean barometric pressure was 27.09 inches, the mean temperature 85° F. The anemometer was held 14 feet above the surface of the ground, or at the elevation of the center of a sail when in its highest position. The wheel is set in a large box the top of which is on a level with the axis of the wheel, to prevent the wind from striking the part of the wheel below its axis. The results of the tests are as follows:

Results of tests of mill No. 20—15½-foot Jumbo.

[Load per stroke, 291.2 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
16 miles	5.3	5.3	13.2	0.047
20 miles	10.7	10.7	26.7	0.095

The curve shown in fig. 19 is seen to be different from the others in that it apparently has no maximum. It starts at a wind velocity of 13

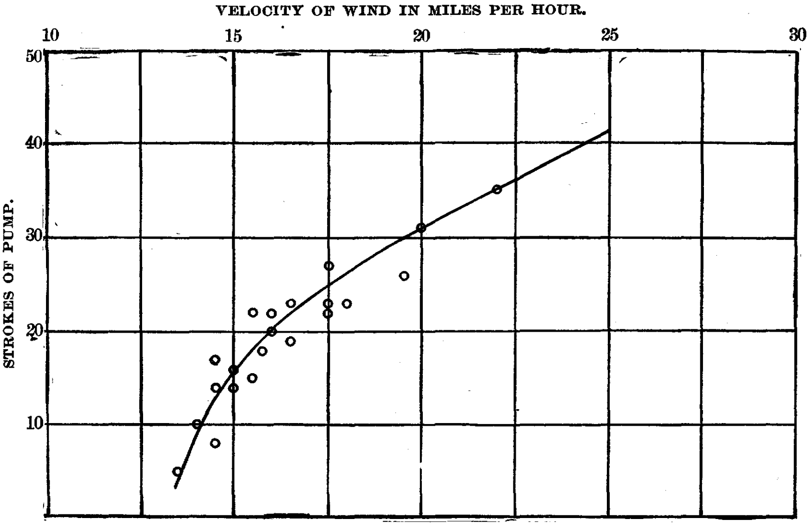
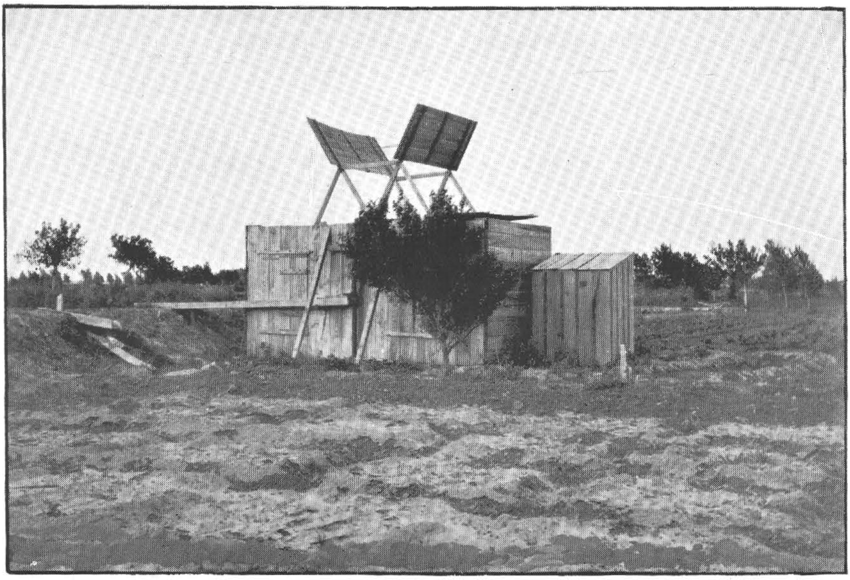
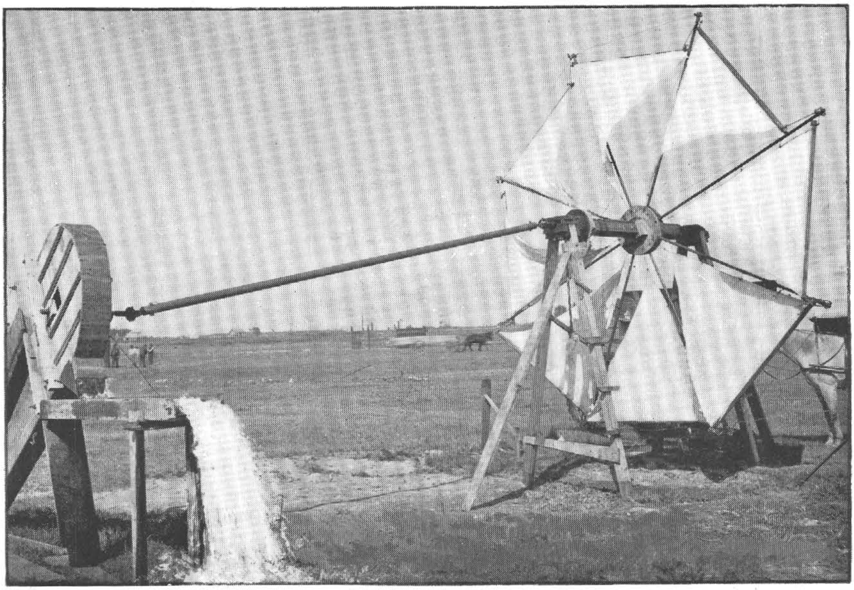


FIG. 19.—Diagram showing results with mill No. 20—15½-foot Jumbo.

to 14 miles, and beyond 20 miles it appears to be a nearly straight line. Comparing these results with those of No. 5, it will be seen that this mill is inferior in power to a good 8-foot steel mill.



A. VIEW OF MILL NO. 20—15½-FOOT JUMBO.



B. VIEW OF DEFENDER MILL AND PUMP KNOWN AS "WATER ELEVATOR."

VIEW OF MILL NO. 21—12-FOOT HALLIDAY.

Mill No. 21.—This is a 12-foot Halliday (shown in Pl. XI) on a 31-foot wooden tower. It was made by the United States Wind Engine and Pump Company, of Batavia, Illinois. The working parts are

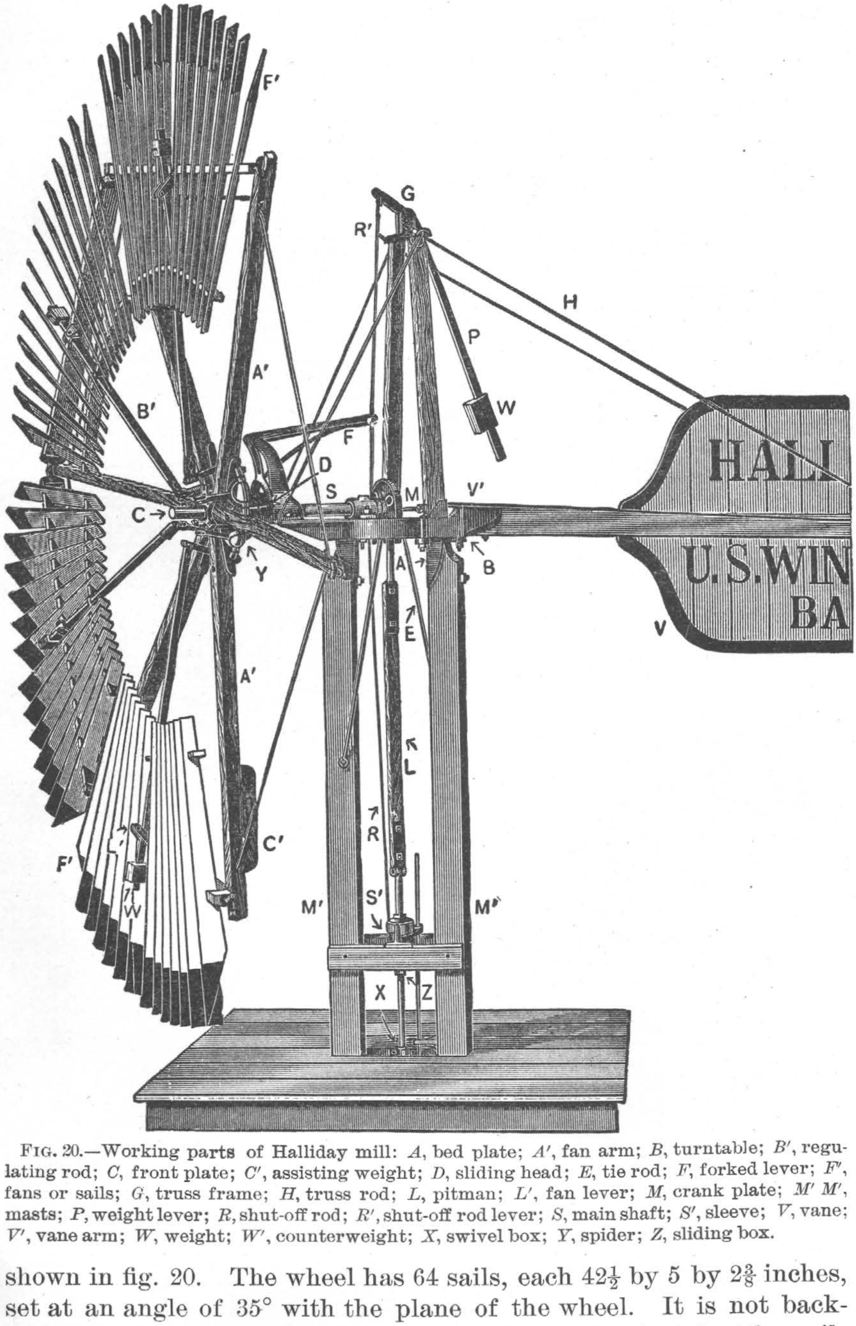


FIG. 20.—Working parts of Halliday mill: *A*, bed plate; *A'*, fan arm; *B*, turntable; *B'*, regulating rod; *C*, front plate; *C'*, assisting weight; *D*, sliding head; *E*, tie rod; *F*, forked lever; *F'*, fans or sails; *G*, truss frame; *H*, truss rod; *L*, pitman; *L'*, fan lever; *M*, crank plate; *M' M'*, masts; *P*, weight lever; *R*, shut-off rod; *R'*, shut-off rod lever; *S*, main shaft; *S'*, sleeve; *V*, vane; *V'*, vane arm; *W*, weight; *W'*, counterweight; *X*, swivel box; *Y*, spider; *Z*, sliding box.

shown in fig. 20. The wheel has 64 sails, each $42\frac{1}{2}$ by 5 by $2\frac{3}{8}$ inches, set at an angle of 35° with the plane of the wheel. It is not back-geared, and regulates itself on the centrifugal principle—the sails taking the direction of the wind. The pump is of the Stone make, with 7½-inch discharge pipe, 4-inch supply pipe, and 7 inches stroke. The check valve is of the lift variety, the plunger valve of the double-flap variety. The well, which is open, is formed by a wooden curb, 12 inches in diameter, sunk in the bottom of a dug well 9 feet deep. The depth to water was 11½ feet and the lift 11 feet. The discharge per stroke was 4½ quarts when pumping quite rapidly (30 strokes per minute). The valves were not in very good repair and the pump lost its priming after a time. The results of the tests are as follows:

Results of tests of mill No. 21—12-foot wooden Halliday.

[Load per stroke, 141.5 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	14.0	14.0	15.9	0.060
16 miles	28.5	28.5	32.1	0.121
20 miles	37.3	37.3	42.0	0.159
25 miles	44.6	44.6	50.2	0.184

This curve (shown in fig. 21), which is for a lightly loaded (141.5 foot-pounds) direct-stroke 12-foot mill, will be seen to start at a wind

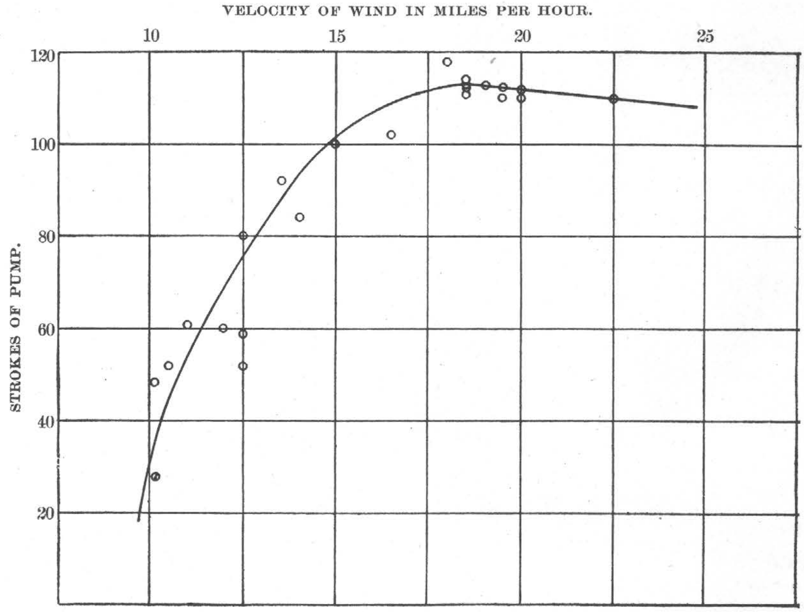


FIG. 21.—Diagram showing results with mill No. 21—12-foot Halliday.

velocity of 9 to 10 miles and to reach a maximum at 19 miles, with a speed of 112 strokes per mile. At 30 miles the number of strokes is about 98 per mile. The number of strokes per minute varies from 14 at 12 miles to 45 at 25 miles. The power of this mill is only about half that of the 12-foot Aermotor, No. 3.

Mill No. 25.—This is an 8-foot steel mill on a 32-foot steel tower, made by Fairbanks, Morse & Company. The wheel has 18 curved sails, each 29 by 11⅝ by 5¼ inches, set at an angle of 29° with the plane of the wheel. It is back-geared, 2½ to 1. The pump is of the common hand variety, with a 2½-inch cylinder, 1½-inch supply and discharge pipes, and 4 inches stroke. The well is open, 6¼ feet to water. The discharge per stroke was 0.31 quart and the lift 8½ feet. The water raised is used for watering stock. The results of the tests are as follows:

Results of tests of mill No. 25—8-foot Fairbanks-Morse steel mill.

[Load per stroke, 5.5 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	30.7	12.3	1.0	0.002
12 miles	73.0	29.2	2.3	0.005
16 miles	93.2	37.3	2.9	0.007
20 miles	95.0	38.0	3.0	0.008
25 miles	83.2	33.3	2.6	0.005

This is a very lightly loaded mill—only 5.5 foot-pounds per stroke of pump. The number of strokes per minute in light winds is large; the number of strokes per minute in a 25-mile wind is only 33.3, compared with 38 in a 20-mile wind. A comparison of this mill with No. 5 will show the difference between a small pumping outfit for stock purposes and one for irrigation.

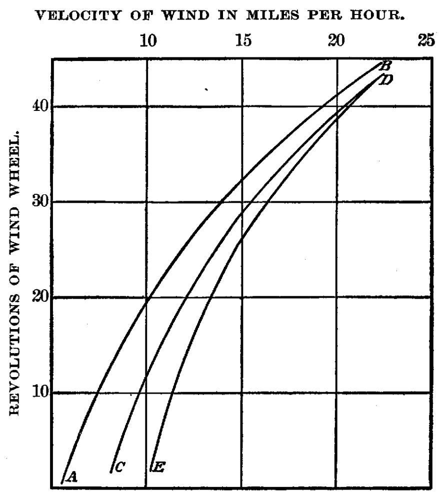


FIG. 22.—Diagram showing revolutions of wind wheel of mill No. 30—16-foot Irrigator. *AB* is for a load of 32 foot-pounds per revolution of wind wheel; *CD* is for a load of 251 foot-pounds; *ED* is for a useful pump load of 337 foot-pounds.

Mill No. 30.—This is a 16-foot Irrigator manufactured by M. Schow, of Kinsley, Kansas. It is a power mill, but not geared forward, and works a pump called a "water elevator." The tower is of wood, 22 feet to axis of wheel. The wind wheel has 10 plane wooden sails, each 70½ by 16 by 13½ inches, set at an angle of 39° to the direction of the wind. The vertical shafting is geared back 30 to 13, and the horizontal shaft is geared forward 13 to 30. The water is lifted from a well 8 feet by 10 feet (7 feet depth to water), cased with wood. The buckets of the elevator are made of galvanized iron and are 14 by 7½ by 5½ inches, set 18 inches center to center, and hold 3 gallons each. Each bucket has a valve in its bottom. The lift is about 11 feet, and there are 20 buckets on the elevator chains. There is a box in the bottom of the well into which the buckets dip to get their supply of water. This box has a screen in its bottom to keep out the sand. The mill does not govern well, on account of side draft. The mean barometric pressure was 27.7 inches, the mean temperature 72° F. The results of the tests are as follows:

Results of tests of mill No. 30—16-foot Irrigator.

Load on brake.	Load per revolution of wind wheel.	Number of revolutions of wind wheel per minute at given wind velocities (per hour).					Useful horsepower at given wind velocities (per hour).				
		8 miles.	12 miles.	15 miles.	20 miles.	25 miles.	8 miles.	12 miles.	15 miles.	20 miles.	25 miles.
Pounds.	*Ft.-lbs.*										
2	32	12	26	33	41	44	0.012	0.025	0.032	0.040	0.043
16	251	....	19	29	39	42	....	0.140	0.220	0.300	0.320
Pump.	337	....	14	26	38	42	....	0.140	0.250	0.400	0.440

Fig. 22 shows the number of revolutions per minute of the wind wheel for three loads. Fig. 23 shows the horsepower for these loads.

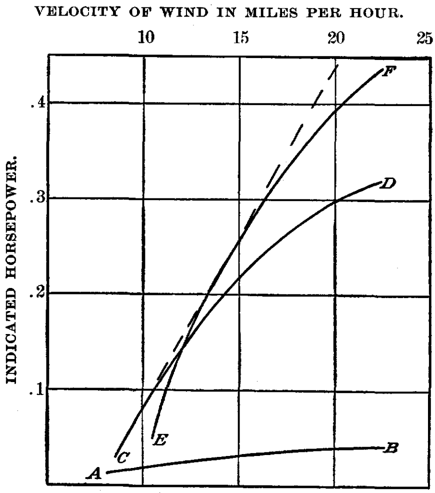


FIG. 23.—Diagram showing horsepower of mill No. 30. Curve *AB* shows the horsepower for a 32 foot-pound load; *CD*, the power for a 251 foot-pound load; *EF*, the power for a 337 foot-pound load; dotted curve shows maximum horsepower for best load.

Comparing the useful pump horsepower of this mill with that of the 16-foot mill No. 9, it will be seen that this mill is not so powerful as No. 9. The power of the Aermotor for low velocities is much greater than that of the Irrigator.

Mill No. 31.—This is a 14-foot Elgin wooden power mill, manufactured at Elgin, Illinois. It works a rotary (Wonder) pump. The wind wheel is on a 48-foot wooden tower. It has 88 plane wooden sails, each 52 by 6 by 3⅛ inches, set at an angle of 37° to the plane of the wheel. It is a sectional vaneless wheel; in place of the vane there is a heavy counterpoise. The wheel is geared forward about 7.19 to 1. The rotary pump is a 3 inch. It is on a well point 6 inches in diameter and 8 feet long; the point penetrates the water to a depth of 8 feet. The lift was about 18 feet. The suction and discharge pipes are each 3 inches in diameter. The discharge was 2 quarts per revolution of pump. The pump is manufactured by the National Pump Company, of Kansas City, Missouri. In a 15-mile to a 20-mile wind the windmill worked the pump before priming, but would not start it in that wind after priming. After several attempts of the mill to start the pump the pulley turned on the shaft so that it could not be used. It was very evident that the pump was too great a load for the mill. The owner stated that the mill would only run during a strong wind.

Mill No. 32.—This mill is like the 12-foot Aermotor, the working parts of which are shown in fig. 7. It is on a 40-foot steel tower. The wheel has 18 curved sails, each 44 by 18¾ by 7¾ inches, set at an angle of 31° to the plane of the wheel. The pump is of the Woodmanse type, a sectional view of which is shown in fig. 5, and has an 8-inch cylinder and 12 inches stroke. It is in an open well. The depth to water was 14 feet, the lift 20 feet, and the discharge per stroke 7 quarts. It is back-geared, 3⅓ to 1. The water is pumped into a pond and used for irrigation. The mean barometric pressure was 27.9 inches, the mean temperature 82° F. The results of the tests are as follows:

Results of tests of mill No. 32—12-foot Aermotor.

[Load per stroke, 313 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	17.7	5.3	9.3	0.047
12 miles	49.3	14.8	25.9	0.131
15 miles	60.0	18.5	32.4	0.164
20 miles	73.0	22.0	38.5	0.195

Mill No. 33—This is a 10-foot Woodmanse pumping mill on a 40-foot steel tower. The working parts are like those shown in fig. 4. The wheel has 24 curved sails, each 30½ by 12½ by 5½ inches, set at an angle of 29° to the plane of the wheel. It is back-geared, 2½ to 1. The pump is of the Woodmanse make (like that shown in fig. 5), with a 6-inch cylinder and 10 inches stroke. The depth to water was 14 feet. The pump is on a well point 3½ inches in diameter, 4 feet long, and 67 feet below the surface of the ground. The suction pipe is 3½ inches in diameter, the discharge pipe 6 inches in diameter. The lift was about 22 feet, the discharge per stroke 3¾ quarts. The water is pumped into a pond and used for irrigation. The mean barometric pressure was 27.9 inches, the mean temperature 88° F.

The results of the tests are as follows:

Results of tests of mill No. 33—10-foot Woodmanse.

[Load per stroke, 173 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	8.7	3.5	3.3	0.020
12 miles	36.0	14.4	13.5	0.075
15 miles	51.2	20.5	19.2	0.110

Mill No. 35.—This is an 8-foot steel Dempster pumping mill, manufactured by the Dempster Manufacturing Company, of Beatrice, Nebraska, and is shown in Pl. XII. The tower is of steel, 30 feet to axis of wheel. The wind wheel has 18 curved sails, each 30½ by 14½ by 7 inches, set at an angle of 27° to the plane of the wheel. It is back-geared, 3 to 1. The well is an open dug well. The distance from the surface of the ground to the water was 39 feet. The water is pumped into a tank 22 feet above ground, and is used for irrigation. The pump has an 8-inch stroke, a 3¼-inch cylinder, and 2-inch suction and discharge pipes. The lift was 58 feet, the discharge per stroke 1.1 quarts. The mean temperature was 51° F., the mean barometric pressure 28.9 inches. The results of the tests are as follows:

Results of tests of mill No. 35—8-foot steel Dempster.

[Load per stroke, 133.5 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
12 miles	57.6	19.2	5.3	0.077
16 miles	86.4	28.8	7.9	0.116
20 miles	99.9	33.3	9.2	0.134

In a 15-mile wind the pump made 26 to 27 strokes per minute, and when the pump rod was uncoupled from the pump it made 34 strokes per minute in the same wind. Fig. 24 shows the number of strokes per minute for different wind velocities. This mill is heavily loaded—133 foot-pounds per stroke of pump. It starts at a wind velocity of about 9 miles an hour, and as the wind increases the number of strokes increases rapidly at first, then more slowly. At 25 miles an hour the number of strokes is 37 per minute. This mill is back-geared, 3 to 1, so that in a 25-mile wind the wind wheel makes 111 revolutions per minute and has a circumference velocity of 46.5 feet per second.

Mill No. 36.—This is a 22½-foot Eclipse wooden pumping mill, lift-

VIEW OF MILL NO. 35—8-FOOT DEMPSTER.

ing water into a tank for railroad purposes. The tower is of wood, 52 feet to the axis of the wheel. The wind wheel has 136 plane sails, each 105 by 6 by 2 inches, set at an angle of 39° to the plane of the wheel. It works by direct stroke. The well, which is open, is 20 feet in diameter; the depth to water was 19 feet from the surface of the ground. The pump is double-acting, and has a 4½-inch cylinder, 7 inches stroke, and 2-inch suction and discharge pipes. The lift was 39 feet. The tank is 90 feet from the well. The discharge could not be measured, but as the packing of the pump was new it was approximately equal to twice the volume of the cylinder, or 0.76 gallon per double stroke. The mean temperature was 58° F., the mean barometric pressure 29.43 inches. The results of the tests are as follows:

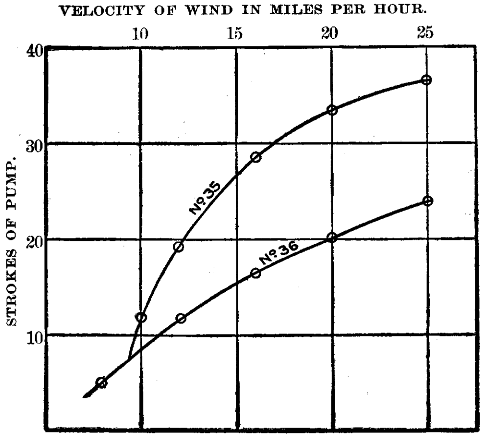


FIG. 24.—Comparative diagram showing results with mills No. 35 (8-foot Dempster) and No. 36 (22½-foot Eclipse).

Results of tests of mill No. 36—22½-foot wooden Eclipse.

[Load per stroke, 248 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	4.8	4.8	3.8	0.036
12 miles	12.0	12.0	9.4	0.090
16 miles	16.5	16.5	12.8	0.124
20 miles	20.0	20.0	15.6	0.150
25 miles	24.2	24.2	18.8	0.182

Fig. 24 shows the strokes per minute at different wind velocities. The diagram is seen to be quite different from that of mill No. 35. The mill starts at a wind velocity of 6 or 7 miles an hour, and increases gradually to 24 strokes in a 25-mile wind. The circumference velocity of the latter is 46.5 feet per second, that of the former 29 feet. The wind wheel of this mill is making 24 revolutions per minute; that of No. 35 is making 111 revolutions per minute in a 25-mile wind.

Mill No. 37.—This is a 12-foot steel Woodmanse Mogul like that shown in fig. 4. It pumps water into a pressure tank 9½ feet by 2½ feet in a cellar and about 170 feet from the well. The pump and pressure tank are shown in fig. 25. The tower is of steel, and is 40 feet to the axis of the wheel. The wind wheel has 30 curved sails, each 37 by 13 by 5.5 inches, set at an angle of 29° to the plane of the wheel. The well is 50 feet deep and 8 inches in diameter; the depth to water was 42 feet. The pump has a 3-inch cylinder and 9 inches stroke. The discharge pipe is 1 inch in diameter, the suction pipe $1\frac{1}{4}$ inches in

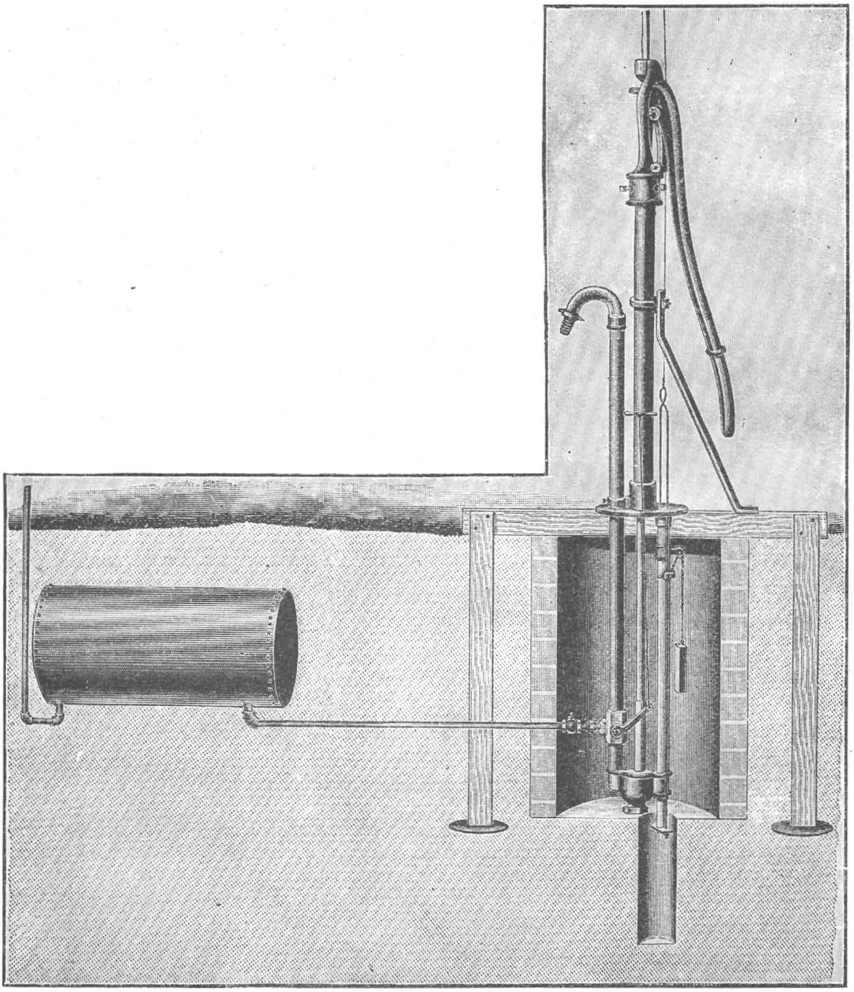


FIG. 25.—Pump, pressure tank, and hydraulic regulator of mill No. 37—12-foot Woodmanse Mogul.

diameter. The discharge per stroke was 1.05 quarts. The load on the pump was equal to 43 feet head of water (the friction in about 200 feet of 1-inch pipe) and a compressed-air pressure the amount of which was recorded on a gage. The mean temperature was 66° F., the mean barometric pressure 29.1 inches. The results of the tests are as follows:

Results of tests of mill No. 37—12-foot steel Woodmanse Mogul.

Load per stroke.	Number of strokes of pump per minute at given wind velocities (per hour).						Useful horsepower at given wind velocities (per hour).					
	8 miles.	12 miles.	16 miles.	20 miles.	25 miles.	30 miles.	8 miles.	12 miles.	16 miles.	20 miles.	25 miles.	30 miles.
Ft.-lbs.												
94	7.7	18.4	24.5	29.3	34.2	38.0	0.022	0.053	0.071	0.083	0.097	0.108
254	......	12.2	19.0	23.3	26.7	29.0	......	0.094	0.146	0.180	0.205	0.223
350	......	......	......	18.0	21.0	21.5	......	......	......	0.191	0.223	0.228
473	......	......	......	10.7	......	......	......	......	......	0.153	......	......

Fig. 26 shows the number of strokes per minute for different wind velocities for four useful pump loads, viz, 43 feet, 43 feet plus 32 pounds, 43 feet plus 50 pounds, and 43 feet plus 75 pounds, or, reducing the pounds pressure to head in feet, the four useful loads are: 43 feet for the curve *aa'*, 116 feet for the curve *bb'*, 160 feet for the curve *cc'*, and 216 feet for the curve *dd'*. The effect of increased load on the number of strokes is well shown here. The effect of the hydraulic regulator may be seen in the curve *cc'*, but it is shown to a greater extent in the curve *dd'*.

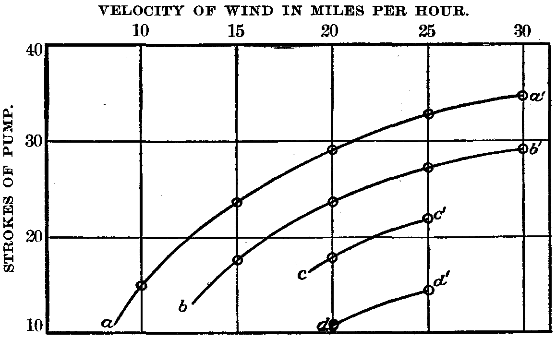


FIG. 26.—Diagram showing results with mill No. 37—12-foot Woodmanse Mogul. The curve *aa'* is for a useful pump load of 43 feet head; *bb'* is for a useful pump load of 116 feet head; *cc'* is for a useful pump load of 160 feet head; *dd'* is for a useful pump load of 216 feet head. The effect of the hydraulic regulator is shown in the curves *cc'* and *dd'*.

Mill No. 38.—This is a 10-foot Woodmanse wooden mill on a 30-foot wooden tower, and is used to pump water for stock. The wind wheel has 96 plane sails, each 34 by $3\frac{1}{2}$ by $1\frac{1}{4}$ inches, set at an angle of 38° to the plane of the wheel. The well is driven and is 107 feet deep; the depth to water was about 44 feet. The pump works direct and has a $2\frac{1}{2}$-inch cylinder and 4 inches stroke. The lift was about 50 feet, and the discharge per stroke of pump $\frac{1}{20}$ gallon.

The results of the tests are as follows:

Results of tests of mill No. 38—10-foot wooden Woodmanse.

[Load per stroke, 21 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	18	18	0.9	0.012
12 miles	29	29	1.5	0.019
16 miles	36	36	1.8	0.023
20 miles	41	41	2.1	0.026
25 miles	46	46	2.3	0.029

Fig. 27 shows the number of strokes per minute for different wind velocities. This is a lightly loaded mill, working direct stroke. It

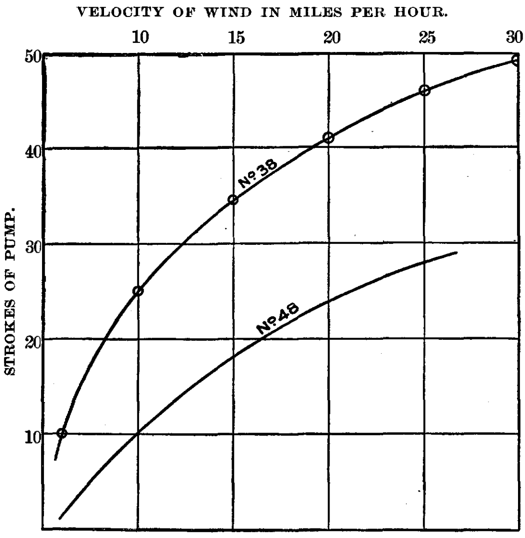


FIG. 27.—Comparative diagram showing results with mills No. 38 (10-foot wooden Woodmanse) and No. 48 (30-foot wooden Halliday).

starts in a 5-mile wind; the number of strokes increases very rapidly at first, and more slowly for high velocities. In a 30-mile wind the number of strokes per minute is 50. The circumference velocity of this wheel in a 25-mile wind is 24 feet per second.

Mill No. 39.—This is a 10-foot Woodmanse direct-stroke iron pumping mill, used to pump water for stock. The tower is of iron, 35 feet to the axis of the wheel. The wind wheel has 18 curved sails, each 30 by 12½ by 7¾ inches, set at an angle of 40° to the plane of the wheel. The pump is on a well point 24 feet below the surface of the ground. It has a stroke of 6 inches, a 3½-inch cylinder, and 1½-inch suction and discharge pipes. The lift was about 27 feet, the discharge per stroke 1 quart. The results of the tests are as follows:

Results of tests of mill No. 39—10-foot iron Woodmanse.

[Load per stroke, 36 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	15	15	3.7	0.017
12 miles	30	30	7.5	0.034
16 miles	40	40	10.0	0.044
20 miles	47	47	11.7	0.052

Mill No. 40.—This is an 8-foot steel pumping mill manufactured by Fairbanks, Morse & Company. It is used to pump water for stock. It is on a 30-foot steel tower. The wind wheel has 18 curved sails, each 29 by 10½ by 5 inches, set at an angle of 29° to the plane of the wheel. It is back-geared, 2½ to 1. The pump is on a well point 20 feet below the surface of the ground. It has a stroke of 6 inches, a 3½-inch cylinder, and 1½-inch suction and discharge pipes. The lift was about 22 feet, and the discharge per stroke $\frac{1}{15}$ gallon. The results of the tests are as follows:

Results of tests of mill No. 40—8-foot Fairbanks-Morse steel mill.

[Load per stroke, 13 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	32.5	13.0	0.8	0.005
12 miles	55.0	22.0	1.5	0.009
16 miles	72.0	29.0	1.9	0.012
20 miles	85.0	34.0	2.3	0.014

Mill No. 41.—This is a 12-foot Woodmanse direct-stroke iron pumping mill, used for pumping water for stock. The tower is of iron, 30 feet to the axis of the wheel. The pump has a 3-inch cylinder and 6 inches stroke. The wind wheel has 24 curved sails, each 36 by 14½ by 7¾ inches, set at an angle of 39° to the plane of the wheel. The lift was 28 feet, and the discharge per stroke ⅛ gallon. The results of the tests are as follows:

Results of tests of mill No. 41—12-foot iron Woodmanse.

[Load per stroke, 29 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	14	14	1.7	0.012
12 miles	25	25	3.1	0.022
16 miles	33	33	4.1	0.029
20 miles	40	40	5.0	0.036

Mill No. 42.—This is a 6-foot Ideal pumping mill on a 22-foot steel tower, and is used for pumping water for stock. It is shown in Pl. XIII. The wheel has 12 curved sails, each 26 by 14½ by 5 inches, set at an angle of 39° to the plane of the wheel. It is back-geared, 4 to 1. The well is a dug well; depth to water, 15 feet. The pump has a 3-inch cylinder and 6 inches stroke. The lift was 16 feet, the discharge per stroke 1 quart. The results of the tests are as follows:

Results of tests of mill No. 42—6-foot Ideal.

[Load per stroke, 35 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	16	4	1.0	0.004
12 miles	52	13	3.2	0.014
16 miles	76	19	4.7	0.020
20 miles	92	23	5.7	0.024

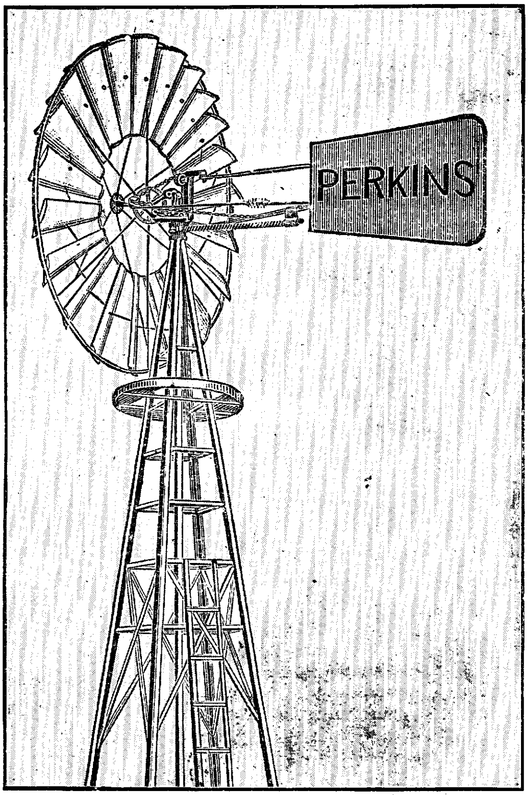
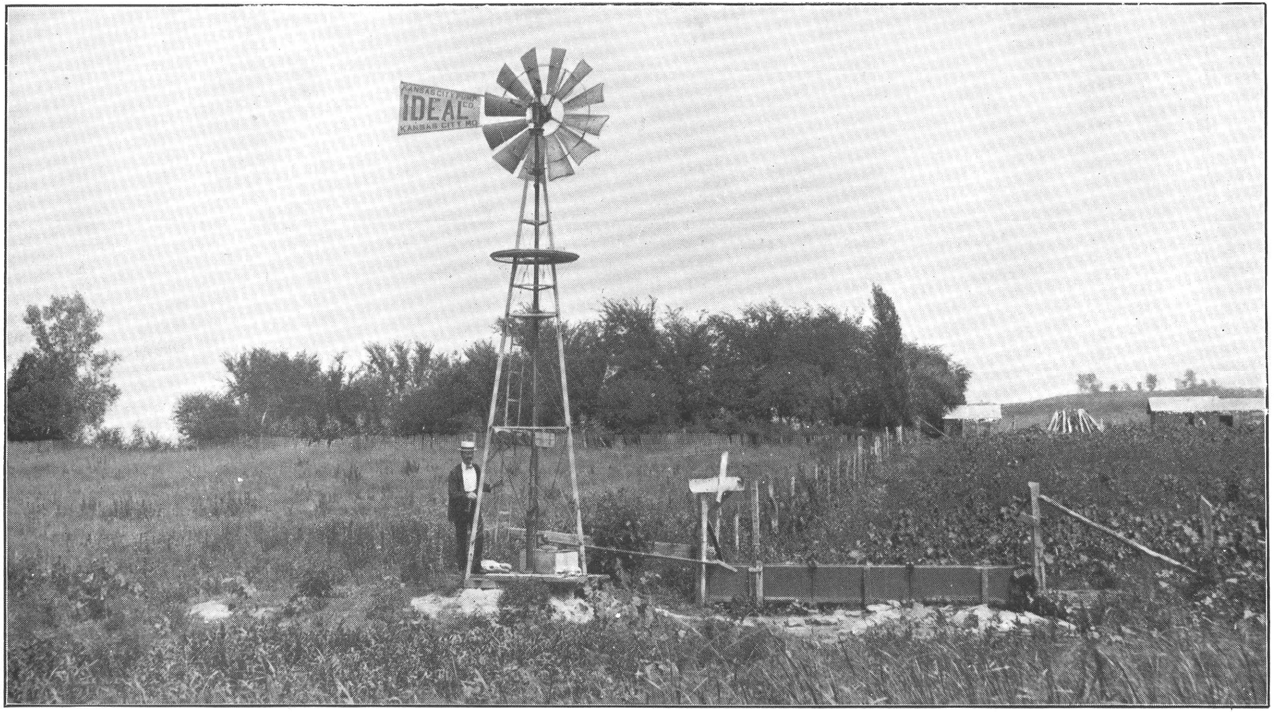


FIG. 28.—View of mill No. 43—10-foot Perkins.

This is the smallest mill yet tested. It is rather heavily loaded for its size; in fact, it is more heavily loaded than the 12-foot mill No. 41. It is doing very good work for a mill of its size.



VIEW OF MILL NO. 42—6-FOOT IDEAL.

Mill No. 43.—This is a 10-foot Perkins direct-stroke pumping mill on a 32-foot steel tower, and is used to pump water for stock. The working parts are shown in fig. 28. The wind wheel has 30 curved sails, each 30 by 10½ by 5 inches, set at an angle of 29° to the plane of the wheel. The pump is on a well point 34 feet below the surface of the ground. It has a 3-inch cylinder and 4 inches stroke. The lift was about 36 feet, the discharge per stroke ½ quart. The exposure was not good. The results of the tests are as follows:

Results of tests of mill No. 43—10-foot Perkins.

[Load per stroke, 37 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	20	20	2.5	0.022
12 miles	32	32	4.0	0.035
16 miles	41	41	5.1	0.045
20 miles	45	45	5.6	0.050

Mill No. 45.—This is a 10-foot Eclipse direct-stroke pumping mill used to pump water for stock. The tower is of wood, 40 feet to the axis of the wheel. The wind wheel has 84 plane sails, each 36½ by 4 by 1½ inches, set at an angle of 35° to the plane of the wheel. The well is a dug well; depth to water, 12 feet. The pump has a stroke of 6 inches, a 3-inch cylinder, and 1½-inch suction and discharge pipes. The lift was 14 feet, and the discharge per stroke 0.62 quart. The results of the tests are as follows:

Results of tests of mill No. 45—10-foot wooden Eclipse.

[Load per stroke, 18 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	18	18	2.8	0.010
12 miles	28	28	4.3	0.014
16 miles	32	32	5.0	0.016
20 miles	35	35	5.4	0.018
25 miles	38	38	5.9	0.019

Mill No. 46.—This is a 10-foot Cornell direct-stroke wooden mill manufactured at Louisville, Kentucky, and is used to pump water for stock. The tower is of wood, 30 feet to the axis of the wheel. The wind wheel has 90 plane sails, each 36 by 4½ by 1½ inches, set at an angle of 47° to the plane of the wheel. The well is a dug well; the water is only about 3 feet below the surface of the ground. The pump has a 3½-inch cylinder and 4 inches stroke. The discharge per stroke was 1 pint when pumping rapidly. The lift was 5⅔ feet. The results of the tests are as follows:

Results of tests of mill No. 46—10-foot wooden Cornell.

[Load per stroke, 6 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	16	16	2.0	0.003
12 miles	25	25	3.1	0.004
16 miles	36	36	4.5	0.006
20 miles	42	42	5.2	0.007
25 miles	48	48	6.0	0.007
30 miles	52	52	6.5	0.008

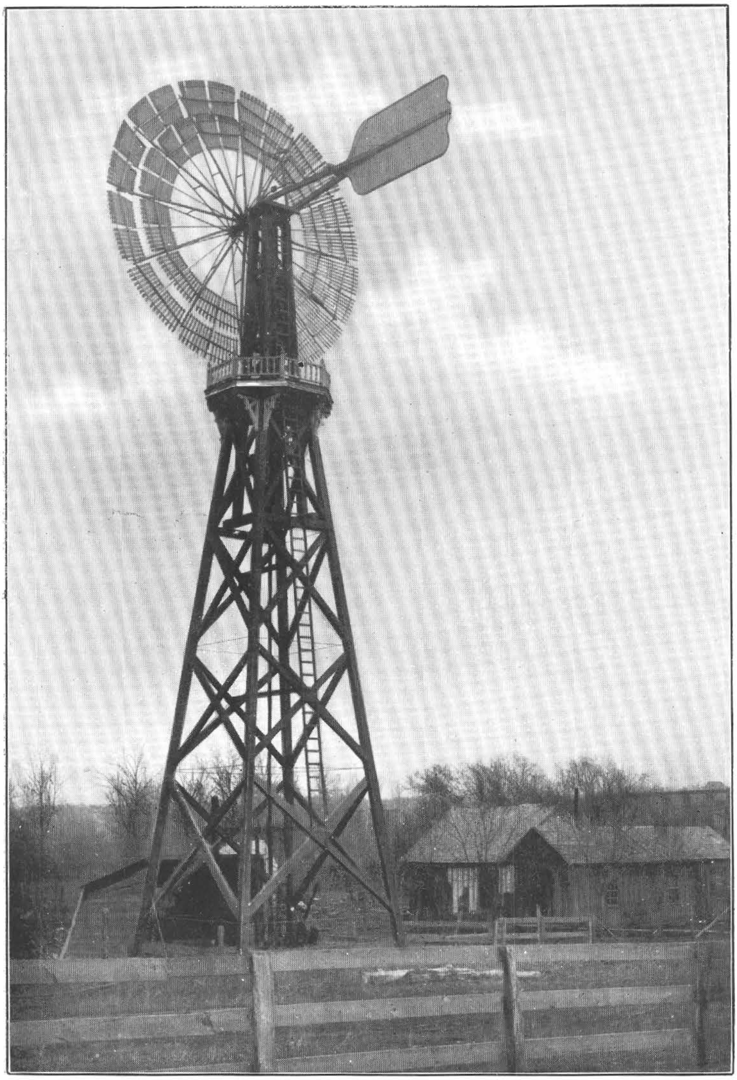
Mill No. 47.—This is a 10-foot Dempster steel mill, like that shown in Pl. XII, on a 40-foot steel tower. The wind wheel has 24 curved sails, each 30½ by 13½ by 6½ inches, set at an angle of 29° to the plane of the wheel. The pump is back-geared, 2⅞ to 1, and has a 3-inch cylinder and 7 inches stroke. The well is open, 20¾ feet to water, and situated under the porch of a house. The mill is located 76 feet from the well. The cylinder is directly under the mill, in a chamber 4 feet by 4 feet, and 6 feet deep. The lower end of the cylinder was about 12 feet vertically above the surface of the water in the well. The discharge per stroke was 1 quart when pumping rapidly. The lift was about 18 feet. The wind wheel of this mill is not well balanced, and the spring which holds it in the wind is not stiff enough. The results of the tests are as follows:

Results of tests of mill No. 47—10-foot steel Dempster.

[Load per stroke, 37 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	37	13	3.2	0.014
12 miles	66	23	5.7	0.026
16 miles	89	31	7.8	0.035
20 miles	95	33	8.3	0.037
25 miles	0	0	0	0.000

A diagram which was platted for this mill shows that the curve drops at about 19 miles an hour, and reaches the axis line at 24 miles. Above 24 miles an hour the wheel is entirely out of the wind and does no work. On this diagram was also platted the number of strokes per minute of the 8-foot Dempster (No. 35), to show the effect of the different loads upon the number of strokes per minute. The 8-foot mill was found to be carrying more than three times the load that the 10-foot mill was carrying.



VIEW OF MILL NO. 48—30-FOOT HALLIDAY.

Mill No. 48.—This is a 30-foot Halliday wooden pumping mill on a 70-foot wooden tower. It is owned by the city of Valley Falls, Kansas, and is used to pump water for the city supply. The mill and tower are shown in Pl. XIV. The sail area is arranged in two concentric rings. In the outer ring there are 192 sails, in the inner ring 144 sails, each 43 by 4½ by 3½ inches, set at an angle of 25° to the plane of the wheel. There are two wells; one (11 feet in diameter) directly under the mill, and another (10 feet in diameter) near the bank of the river 375 feet from the mill. A 3-inch suction pipe connects the wells, and a 3-inch supply pipe leads from the lower well to the river. The pump is double-acting, and has a 4-inch cylinder and 11 inches stroke. The water is pumped directly into the distribution pipes, also into an elevated tank. The tank is of wood, 20 feet by 30 feet, and is 5,570 feet distant from the mill. Of the connecting pipe, 50 feet is 3 inches in diameter, 1,200 feet is 4 inches in diameter, and 4,300 feet is 6 inches in diameter. The bottom of the tank is 111 feet above the well platform. The lift or head at any time is, then, the distance from the well to the well platform and 111 feet plus the amount registered on the gage on the tank. The mean lift when the test was made was 135 feet. The cylinder capacity is 2.4 quarts, the measured discharge per double stroke 4.5 quarts. The mean temperature was 90° F., the mean barometric pressure 28.9 inches. The results of the tests are as follows:

Results of tests of mill No. 48—30-foot wooden Halliday.

[Load per stroke, 1,265 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horse-power.
8 miles	6	6	6.7	0.23
12 miles	15	15	16.9	0.58
16 miles	20	20	22.5	0.77
20 miles	24	24	27.0	0.92
25 miles	28	28	31.5	1.07

This windmill and pump had been in use about ten years. It furnishes enough water during nine months in the year, but during the months of July and August and part of June and September a steam engine is at times employed to work the pump. The cost of repairs to the mill and pump has been from $50 to $60 a year. The number of strokes per minute for different wind velocities is shown in fig. 27.

This is the largest windmill pumping outfit that we have tested. It is interesting to compare its power with that of the smaller wooden mills and with that of the steel mills.

Mill No. 51.—This is an 8-foot Monitor steel pumping mill on a 30-foot steel tower (see fig. 29). The wind wheel has 18 curved sails, each 31½ by 13 by 5 inches, set at an angle of 35° with the plane of the wheel. The well is a dug well; depth to water, $18\frac{1}{2}$ feet. The water is used for stock. The pump has a 3-inch cylinder, 6 inches stroke, and $1\frac{1}{2}$-inch suction and discharge pipes. The cylinder is 1 foot above the lower end of the suction pipe, and is always under water. A peculiarity of this mill is that the downstroke of the pump

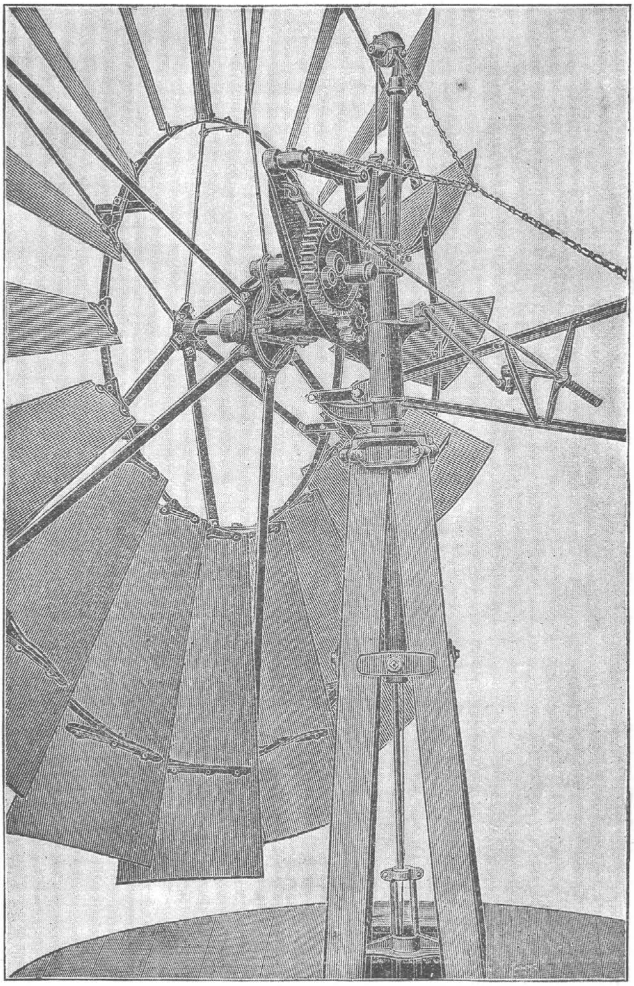


FIG. 29.—Working parts of mill No. 51—8-foot Monitor.

is made in less time than the upstroke. The mill is back-geared, 35 to 13, 13 of the cogs being passed over on the downstroke and 22 on the upstroke. This arrangement makes the mill run easily and prolongs its usefulness. The wind wheel is held in the wind by the weight of the tail; there is no spring. The lift was 25 feet, the discharge per stroke 0.7 quart. The mean temperature was 84° F., the mean barometric pressure 27.8 inches. The results of the tests are as follows:

Results of tests of mill No. 51—8-foot steel Monitor.

[Load per stroke, 36.5 foot-pounds.]

Wind velocity per hour.	Revolutions of wind wheel per minute.	Strokes of pump per minute.	Gallons pumped per minute.	Useful horsepower.
8 miles	27	10	1.7	0.011
12 miles	56	21	3.7	0.023
16 miles	81	30	5.2	0.034
20 miles	91	34	6.0	0.037

When the mill was running uncoupled from the pump, the pump rod made 24 strokes per minute in a 12-mile wind, i. e., the pump load of 36.5 foot-pounds per stroke reduced the number of the strokes of the pump rod from 24 to 21.

For the purpose of ready comparison the principal results of these tests of pumping mills have been tabulated. (See table on p. 64.)

DISCUSSION OF RESULTS OF TESTS.

In this discussion of the results of the tests of these pumping mills we wish to call attention to the principal facts shown by them. The explanation of some of the points is not easy. The useful work which a windmill will do at a given wind velocity depends on several factors, and it is difficult to measure or even estimate the value of each. If the mills could be tested under conditions easily controlled by the experimenter, the problem would be greatly simplified; but each mill is tested under its own conditions of pump, well, wind exposure, and atmosphere. A comparison of the results of the tests of pumping mills with the results of the tests of power mills throws much light on some of the facts (see Part II, pages 107 to 109, inclusive). A fact very evident from the following table is that the useful work done by windmills in pumping water is small. Only one mill, the largest (No. 48), is doing 1 horsepower of useful work in a 25-mile wind. The best 12-foot mill is doing less than 0.64 horsepower and the best 8-foot mill less than 0.12 horsepower in a 25-mile wind.

Results of tests of pumping mills.

No. of mill.	Name of mill.	Size of mill.	Size of pump. *b*	Lift of pump.	Useful work per stroke.	Number of strokes of pump per minute at given wind velocities (per hour).						Useful horsepower at given wind velocities (per hour).					
						8 miles.	12 miles.	16 miles.	20 miles.	25 miles.	30 miles.	8 miles.	12 miles.	16 miles.	20 miles.	25 miles.	30 miles.
		Feet.	*Inches.*	*Feet.*	*Ft.-lbs.*												
2	Woodmanse	12	9⅝x12	17.75	536.2	......	5.2	16.0	20.3	23.3	25.3	......	0.085	0.260	0.322	0.379	0.411
3	Aermotor	12	9½x12	13.75	415.3	5.3	12.0	16.4	19.8	23.1	25.0	0.067	0.151	0.207	0.250	0.291	0.315
4	Ideal	8	5⅝x 8	12.00	50.0	......	10.2	19.3	25.3	28.1	25.0	......	0.015	0.029	0.038	0.043	0.038
5	Aermotor	8	6 x 8	13.00	94.9	......	18.6	25.1	29.8	34.6	38.5	......	0.053	0.072	0.086	0.099	0.111
6	Gem	8	6⅛x 8	9.60	77.6	......	12.4	17.9	22.0	25.4	28.5	......	0.029	0.042	0.051	0.059	0.065
7	Aermotor	12	9½x12	15.50	461.9	......	11.4	15.8	19.0	22.1	23.5	......	0.160	0.221	0.266	0.309	0.329
8	Star (*a*)	10	3 x 5	30.00	15.0	28.0	30.0	......	......	......	......	0.013	0.014	......	......	......	......
9	Aermotor	16	8 x16	44.25	1,013.0	......	10.6	14.1	17.2	19.6	21.0	......	0.325	0.433	0.448	0.601	0.644
10	Ideal	8	2½x 6	33.00	22.8	14.1	25.0	33.3	......	......	......	0.010	0.017	0.023	0.032	......	......
11	.....do	12	7⅞x12	45.00	843.7	......	4.8	12.7	18.8	23.3	25.0	......	0.123	0.325	0.481	0.600	0.639
12	.....do	14	9½x12	11.00	263.5	3.1	10.9	15.7	19.2	21.5	......	0.025	0.087	0.125	0.153	0.172	......
13	Aermotor	12	10 x12	11.00	330.0	......	11.0	17.1	21.0	24.6	27.5	......	0.110	0.171	0.210	0.247	0.275
15	Gem	10	8 x 8	15.00	219.0	......	7.8	11.9	14.7	14.6	......	......	0.053	0.082	0.101	0.099	......
16	Halliday (*a*)	10	6 x 8	16.00	100.0	4.0	22.6	33.9	42.7	52.5	......	0.012	0.067	0.103	0.130	0.159	......
17	Gem	12	8 x12	21.75	38.5	......	6.0	12.8	17.3	......	......	......	0.070	0.149	0.202	......	......
18	Ideal	8	5½x 8	14.75	89.2	8.0	20.2	26.1	28.0	27.5	......	0.022	0.054	0.070	0.076	0.074	......
19	Gem	12	10 x10	18.00	450.0	......	6.2	11.9	14.7	16.0	......	......	0.085	0.162	0.201	0.219	......
20	Jumbo (*a*)	15½	6 x12	14.00	291.2	......	......	5.3	10.7	17.5	......	......	......	0.047	0.095	0.154	......
21	Halliday (*a*)	12	7⅝x 7	15.00	141.5	......	14.0	28.5	37.3	44.6	......	......	0.060	0.121	0.159	0.184	......
25	Fairbanks	8	2½x 4	8.50	5.5	12.3	29.2	37.3	38.0	33.3	......	0.002	0.005	0.007	0.008	0.005	......
30	Irrigator (*a*)	16	......	14.00	......	......	......	......	......	......	......	......	0.14	0.25	0.40	0.44	......
32	Aermotor	12	8 x12	20.00	313.0	5.3	14.8	19.0	22.0	......	......	0.047	0.131	0.170	0.195	......	......
33	Woodmanse	10	6 x10	22.00	172.0	3.5	14.4	20.5	......	......	......	0.020	0.075	0.110	......	......	......
35	Dempster	8	3½x 8	58.00	133.5	......	19.2	28.8	33.3	......	......	......	0.077	0.116	0.134	......	......
36	Eclipse (*a*)	22½	4½x14	39.00	248.0	4.8	12.0	16.5	20.0	24.2	......	0.036	0.090	0.124	0.150	0.182	......
37	Woodmanse	12	3 x 9	......	254.0	......	12.2	19.0	23.3	26.7	29.0	......	0.094	0.146	0.180	0.205	0.223
38	.....do. (*a*)	10	2½x 4	50.00	21.0	18.0	29.0	36.0	41.0	46.0	......	0.012	0.019	0.023	0.026	0.029	......
39	.....do	10	3½x 6	27.00	36.0	15.0	30.0	40.0	47.0	......	......	0.017	0.034	0.044	0.052	......	......
40	Fairbanks	8	3½x 6	22.00	13.0	13.0	22.0	29.0	34.0	......	......	0.005	0.009	0.012	0.014	......	......
41	Woodmanse	12	3 x 6	28.00	29.0	14.0	25.0	33.0	40.0	......	......	0.012	0.022	0.029	0.036	......	......
42	Ideal	6	3 x 6	16.50	35.0	4.0	13.0	19.0	23.0	......	......	0.004	0.014	0.020	0.024	......	......
43	Perkins	10	3 x 4	36.00	37.0	20.0	32.0	41.0	45.0	......	......	0.022	0.035	0.045	0.050	......	......
45	Eclipse (*a*)	10	3 x 6	14.00	18.0	18.0	28.0	32.0	35.0	......	......	0.010	0.014	0.016	0.018	......	......
46	Cornell (*a*)	10	3½x 4	5.70	6.0	16.0	25.0	36.0	42.0	48.0	52.0	0.003	0.004	0.006	0.007	0.007	0.008
47	Dempster	10	3 x 7	18.00	37.0	13.0	23.0	31.0	33.0	0	0	0.014	0.026	0.035	0.037	0	0
48	Halliday (*a*)	30	4 x22	135.00	1,265.0	6.0	15.0	20.0	24.0	28.0	......	0.23	0.58	0.77	0.92	1.07	......
51	Monitor	8	3 x 6	25.00	36.5	10.0	21.0	30.0	34.0	......	......	0.011	0.023	0.034	0.037	......	......

a Wooden mills.

b Inside diameter of cylinder by length of stroke.

From the foregoing table it will be seen that mills of the same size differ very much in the amount of useful work, and that some of the larger mills are doing very little more work than some of the smaller ones. Nos. 4 and 18, for example, are the same size and make (the wells, however, are very different), but the latter is doing three or four times more work than the former. The 12-foot mill, No. 11, is doing nearly as much useful work as the 16-foot mill, No. 9, and three or four times more work than the 14-foot mill, No. 12, while it is doing 300 per cent more work than No. 21. The 15½-foot Jumbo will probably do little more work during the season than a good 8-foot mill.

RELATION BETWEEN WIND VELOCITY AND STROKES OF PUMP.

Figs. 6, 10, 11, 12, 13, 15, 17, 18, 19, and 21 show graphically the relation between the wind velocity (in miles per hour) and the strokes of the pump. The curves, as will be noted, differ considerably; but with the exception of fig. 19, for mill No. 20, they agree in that they rise rapidly, reaching the highest point at wind velocities of from 13 to 19 miles. From that point they descend slowly. They differ much in the position of the beginning of the curve, or the velocity required to start the mill. Some will run in an 8-mile wind, while others require a 10-mile or a 12-mile wind to start them. Some rise less rapidly than others, a notable case being mill No. 11. Some descend much more rapidly than others after reaching the highest point. This is especially true of the 8-foot Ideals. Mill No. 20 required a 14-mile wind to start it, and does not appear to have a maximum. The shape of the curve, especially the position of its initial point, is due to the load on the pump, or the number of foot-pounds per stroke. An increase in the load moves the curve to the right and raises it higher. This will be more clearly shown in Part II (see discussion on 12-foot power mill No. 27, pp. 86–89). The height and position of the highest point depend on the tension of the spring, or the weight which holds the mill in the wind. The greater the tension the higher the summit and the farther it is to the right; the less the tension in the spring the steeper the descent from the highest point. The gearing—i. e., the mechanism which causes the pump to make a stroke to each revolution of the wheel, or a stroke every second or third revolution only—modifies the curve. In mills with a direct stroke the curve is much higher and is farther to the right than in back-geared mills, as shown by a comparison of the curves of mills Nos. 3 and 21, shown in figs. 10 and 21.

USEFUL WORK OF PUMPING MILLS.

The relation between wind velocity and horsepower is shown graphically, for five 12-foot mills in fig. 30, and for four 8-foot mills in fig. 31. Examining the five curves of fig. 30, we see that No. 11, the one which gives the greatest horsepower, has the heaviest load and requires the greatest wind velocity to start it. No. 2 has about five-eighths of the load of No. 11, does less work, and requires about the same wind velocity to start it. No. 3 has a lighter load than No. 2, and will start in a wind of about 7 miles an hour. No. 19 has a little heavier load than No. 3, and does much less work at all velocities. The latter requires a 9-mile or a 10-mile wind to start it, while the former will start in a 7-mile or an 8-mile wind. No. 21 is doing the least work of the five, and requires about an 11-mile wind to start it. It is a wooden mill working direct stroke, while the others are steel mills and back-geared.

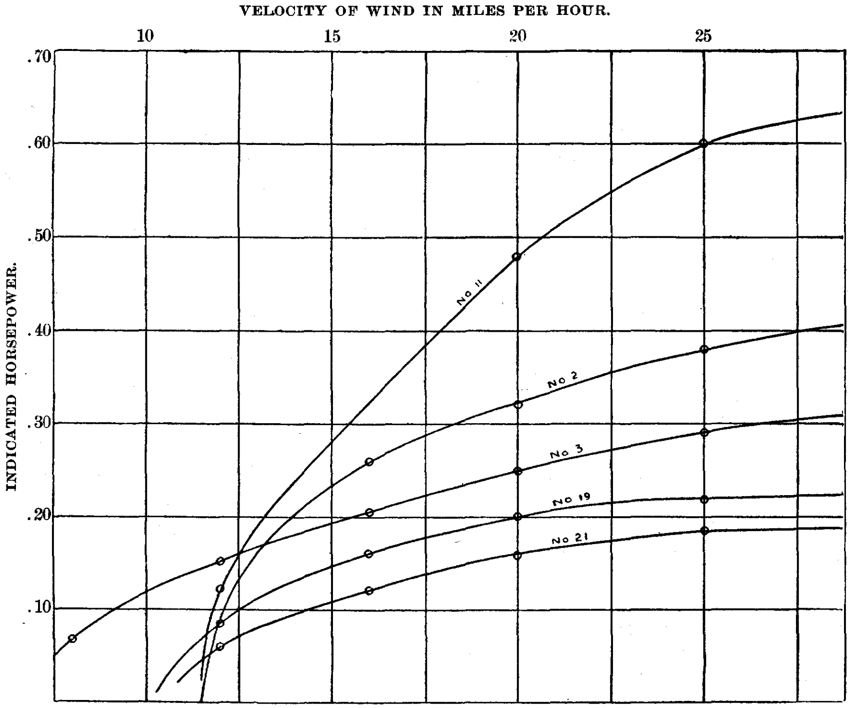


FIG. 30.—Diagram showing relation between horsepower and wind velocity for five 12-foot mills.

It must be understood that in this comparison no correction or allowance is made for the difference in temperature and barometric pressure, nor for the fact that in the case of Nos. 11 and 19 the pumps are on well points, while in the others they are in open wells.

It will be seen that none of the curves in fig. 30 reach a maximum below 30 miles an hour. They do, however, for some higher velocities, since the work per stroke of pump is nearly constant for each pump for all velocities, though not the same for one pump as for another. The curves also give the relation between wind velocity and the number of strokes of pump per minute.

In fig. 31 the curve for No. 18 is seen to reach a maximum at about 25 miles an hour. The others reach their maximum points at velocities of about 30 miles an hour. These maximum points are points of greatest speed, and are produced by a reduction of wind area, the wind wheel turning out of the wind. This make of mill is seen to "govern," or turn out of the wind, at a lower velocity than other makes.

Comparing the curves in fig. 31, we see that the pump doing the most work at high wind velocities is No. 5, which is also the one most heavily loaded. The principal differences between Nos. 4 and 18, the pumps doing the most and the least work for velocities less than 22 miles an hour, are in the load and the well. No. 4 has five-ninths of the load of No. 18, and is on a well point. The two pumps doing the least work are on well points.

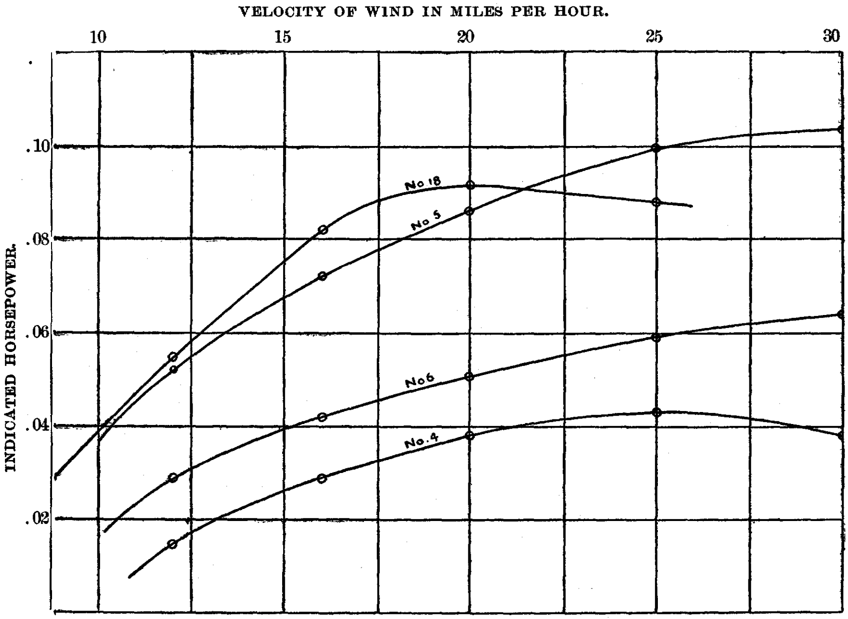


FIG. 31.—Diagram showing relation between horsepower and wind velocity for four 8-foot mills.

Mill No. 25 is used to pump water for stock. Comparing it with, say, No. 5, we find that its load is about five-ninths as great, and that it is doing about one-tenth as much work as the latter. It will start with a wind velocity of about 6 miles an hour, while the latter requires a wind velocity of about 8.5 miles an hour.

It is interesting to compare the results of Nos. 35 and 36. The former is an 8-foot back-geared steel mill, heavily loaded; the latter is a 22.5-foot direct-stroke mill, lightly loaded. The wind exposure of both is very good. The discharge per stroke of No. 35 is 1.1 quarts, that of No. 36 about 3 quarts. The lift of the former is 58 feet, the lift of the latter 39 feet. The load per stroke of the former is 133 foot-pounds, that of the latter 248 foot-pounds. No. 35 starts in about a

9-mile wind, No. 36 in a 6-mile wind. In an 8-mile wind the former is doing no work, the latter is making 4.8 strokes per minute; but in a 12-mile wind the former is making 19 strokes per minute, the latter only 12; for all higher velocities the former is making 60 per cent more strokes than the latter. For wind velocities above 12 miles an hour the horsepower of the 22.5-foot mill is only from 7 to 17 per cent greater than that of the 8-foot mill. The difference is really not so great as this, as the actual discharge is not so great as we have supposed.

PRESSURE-TANK SYSTEM.

Mill No. 37 is of special interest, in that the water is forced into a pressure tank instead of into an elevated tank. This system is said to be in use to some extent in the Eastern States, and is just coming into use in the West. The advantage claimed for it is that the tank can be placed in a cellar or under ground, where it will not freeze, instead of on an elevated structure. A hydraulic regulator is used, which causes the mill to turn out of the wind when the pressure in the tank reaches a certain amount. In this case the tank, which is located in a cellar, is 2 feet in diameter and 9.5 feet long; it is about 170 feet from the well and about 43 feet above the surface of the water in the well. The discharge (1.05 quarts per stroke) is pumped into the tank, then forced by the confined air through a 1-inch iron pipe to the hydrants, then through a line of rubber hose to the desired point. The pressure in the tank diminishes with the reduction in the quantity of water in it. For different volumes of air it is as follows:

Pressures in tank for different volumes of air.

Air volume.	Pressure.
Barrels.	*Pounds.*
11.1	0
5.6	14.7
3.7	29.4
2.8	44.1
2.2	58.8
1.9	73.5
1.6	88.2
1.4	103.0

The objection to this system can easily be seen from this table. When the pressure is 103 pounds per square inch the withdrawal of 0.2 barrel of water from the tank lowers the pressure to 88.2 pounds, and the withdrawal of an additional 0.3 barrel lowers the pressure to 73.5 pounds; in other words, the withdrawal of a half barrel of water when the pressure is 103 pounds lowers the pressure 30 pounds. We found, on trial, that when the pump was not working (no wind), and the pressure was at 59 pounds, one hose stream through a $\frac{3}{16}$-inch nozzle reduced the pressure to 50 pounds in one minute and to 45 pounds in two minutes. In seven minutes it fell to 30 pounds, and in seventeen minutes from the time of opening the cock it fell to 20 pounds. In a 20-mile to 30-mile wind, and with one hose stream running, the pump kept the pressure in the tank at about 30 pounds. Where only a small amount of water is needed at a time this system will probably give satisfaction. By the use of a larger tank more water can be obtained for a given reduction of pressure.

It will be noticed that this is the same size and make of mill as No. 2, but that it is altogether different from No. 41. No. 2 is more heavily loaded than No. 37. The heaviest load on No. 37 is 472 foot-pounds per stroke of pump; the heaviest load on No. 2 is 536 foot-pounds per stroke. No. 2 is doing the most useful work, but the hydraulic regulator acts on No. 37 to turn it partly out of the wind for the load 43 plus 75 pounds. No. 41 is doing very little work, but it is lightly loaded and working direct stroke.

COMPARISON OF THREE PUMPING AERMOTORS.

Comparing the 16-foot Aermotor No. 9, the 12-foot Aermotor No. 3, and the 8-foot Aermotor No. 5, a diagram was plotted of the horsepower of these three mills, drawn to the same scale. They were found to start at about the same wind velocity, viz, 7 miles an hour, which indicates about the same total load. In a 25-mile wind the 8-foot mill was found to be yielding 0.1 horsepower, the 12-foot mill 0.29 horsepower, and the 16-foot mill 0.6 horsepower. In other words, the 12-foot mill was doing about three times and the 16-foot mill about six times more work than the 8-foot mill. The conclusion can not be drawn from this that the powers of the mills are to each other in these ratios, since the pump efficiencies are not the same.

USEFUL WORK OF TWO PUMPING MILLS IN A GIVEN TIME.

The useful work which two pumping mills of the same wind area, exposure, pump efficiency, and general character will do depends on the load on the mill and the wind velocity. If the mill is heavily loaded it will do more work at wind velocities of 12 or more miles an hour and less work at lower velocities than one of lighter load. The useful work done in a given time is the product of the work done per hour at the mean velocity multiplied by the number of hours. If the mean velocity at a given place is low, the mill load must be less for maximum work than that at a place where the mean velocity is higher. To illustrate this fact, we will use the results of the tests of two 12-foot pumping mills—No. 11, heavily loaded and giving a greater horsepower at high wind velocities than any other mill tested, and No. 3, giving the greatest power at low velocities. The useful work per stroke of pump is 844 foot-pounds for No. 11 and 415 foot-pounds for No. 3. The useless work of the former is greater than that of the latter, since the pump of the former is on two well points, while the pump of the latter is in an open well. The relation between the horsepower and the wind velocity is shown in fig. 30. The curves are seen to cross each other at a wind velocity of 12.5 miles an hour. For less velocities than that No. 3 is doing more work per hour than No. 11, and for greater velocities No. 11 is doing more work than No. 3. If the velocity were, say, not more than 13 miles an hour, it is very evident that mill No. 3 would do more work in a given time than mill No. 11.

There is no record of wind movement at Garden, Kansas (where most of these tests of pumping mills were made), for any considerable length of time. There is one, however, for Dodge, 50 miles east of Garden, kept by the United States Weather Bureau, which may be used for this purpose. The following table gives the number of hours per month for the six months April to September, for the years 1889 to 1895, inclusive, when the wind movement was, respectively, 0 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25, 26 to 30, 31 and more miles per hour.

Mean wind movement at Dodge, Kansas, for the seven years 1889 to 1895.

Month.	0–5 miles.	6–10 miles.	11–15 miles.	16–20 miles.	21–25 miles.	26–30 miles.	31 and greater.
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
April	116	175	157	113	76	43	40
May	116	195	168	120	74	39	32
June	120	187	139	111	86	49	28
July	144	218	176	117	57	23	9
August	178	230	152	99	62	18	5
September	166	182	152	93	75	34	18
Mean	140	198	157	109	72	34	22

It will be seen from this table that the wind velocity at Dodge is 5 miles or less per hour for 140 hours per month. During this time neither of these mills (Nos. 3 and 11) will do any work, as neither will start in a 5-mile wind.

The velocity is from 6 to 10 miles an hour for 198 hours a month. Mill No. 3 will start in about a 7-mile wind, and hence will run about four-fifths of this time, or 158 hours. No. 11 requires 11.5 miles of wind to start it, and will do no work during this time.

The velocity is 11 to 15 miles an hour for 157 hours during the month. No. 3 will work all of this time, and No. 11 about nine-tenths of the time, or 141 hours.

Both mills will run at all higher velocities. At Dodge, mill No. 3 will run (if in the wind) about 75 per cent of the time, and No. 11 about 51 per cent of the time. For convenience, these results have been tabulated.

Comparative results of tests of two pumping mills.

Wind velocities, miles per hour.	Mill No. 3.			Mill No. 11.		
	Hours per month.	Horse-power.	Product.	Hours per month.	Horse-power.	Product.
6 to 10	158	0.067	10.6	0	0.00	0.0
11 to 15	157	0.168	26.4	141	0.19	26.8
16 to 20	109	0.230	25.1	109	0.40	43.6
21 to 25	72	0.277	19.9	72	0.56	40.3
26 to 30	34	0.308	10.5	34	0.63	21.4
31 and greater	22	0.320	7.0	22	0.64	14.1
Total			99.5			146.2

The second and fifth columns in this table give the number of hours during the mean month that each mill will run with a wind velocity of from 6 to 10 miles an hour. The third and sixth columns give the horsepower for the mean velocity; for example, 0.168 is the horsepower for No. 3 at a wind velocity of 13 miles an hour, and 0.19 is the horsepower for No. 11 at the same velocity. The fourth and seventh columns (the product of the number of hours and the horsepower) give the horsepower that each mill will yield during the month. It will be seen that No. 11 is doing 31 per cent more useful work than No. 3. If this comparison be made for the month of August, it will be found that No. 11 will do 26 per cent more useful work during that month than No. 3.

PROPER LOAD.

It will be seen from what has just preceded, that the useful power of a pumping mill depends to a great extent on its load. If the water is needed constantly and there is little or no storage, as in the case of water for stock, the mill must be lightly loaded, and the useful work it will do is small. If, however, there is plenty of storage, the mill will pump the largest amount of water if heavily loaded. If there were some automatic device for increasing the load on the mill as the wind velocity increases, the problem of proper load would be solved. But such a device seems difficult to construct.

The following table gives data for back-geared steel irrigating mill and good pumps for use in the semiarid regions of the West, especially for Kansas and Nebraska.

Data regarding mills and pumps for use in semiarid regions.

Diameter of mill.	Load per stroke.	Quantity delivered per stroke.	Lift.	Cylinder capacity.	Starting wind velocity (per hour).	Speed per minute in 20-mile wind.	Discharge per hour.	Discharge per 24 hours.
Feet.	*Ft.-lbs.*	*Quarts.*	*Feet.*	*Inches.*	*Miles.*	*Strokes.*	*Gallons.*	*Acre-ft.*
8	125	2.0	30	4.5× 8	9	27	810	0.059
12	600	9.6	30	8×12	8 to 9	20	2,880	0.212
16	1,100	17.6	30	9×16	7 to 8	16	4,224	0.311

For half this lift, or 15 feet, the cylinder capacity should be nearly doubled, and for double the lift the cylinder capacity should be about half that given in the table.

In Part II of this paper, published as Water-Supply and Irrigation Paper No. 42, will be found a discussion of the writer's experiments with power mills, a comparison of pumping mills with power mills, a discussion of the effect of tension of spring on the horsepower of mills, a mathematical discussion of the tests of two Aermotors, a discussion of the action of air on the sail of an Aermotor, a discussion of the useful work of two power mills in a given time, discussions of the results of tests of a Jumbo mill and of a Little Giant mill, a comparison of the Little Giant and Jumbo mills, a comparison of the Little Giant mill and the 8-foot Aermotor, a discussion of the indicated and true velocities of windmills, a comparison of the writer's experiments with those of other experimenters, and economic considerations.

[For index see end of Part II, Water-Supply Paper No. 42.]

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert: "The water resources of Illinois," by Frank Leverett, and "Preliminary report on the artesian waters of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the calendar year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton, and "Reservoirs for irrigation," by J. D. Schuyler.

1899.

Nineteenth Annual Report of the United States Geological Survey, 1897–98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton, and "A preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

1900.

Twentieth Annual Report of the United States Geological Survey, 1898–99, Part IV, Hydrography, 1900; octavo, 660 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell, and "Hydrography of Nicaragua," by A. P. Davis.

WATER-SUPPLY AND IRRIGATION PAPERS, 1896–1900.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost, as noted above. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Postage stamps, checks, and drafts can not be accepted. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Underground waters of southeastern Nebraska, by N. H. Darton, 1898.
13. Irrigation systems in Texas, by W. F. Hutson, 1898.
14. New tests of pumps and water lifts used in irrigation, by O. P. Hood, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.
17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
20. Experiments with windmills, by Thomas O. Perry, 1899.
21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems of Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.
25. Water resources of the State of New York, Part II, by George W. Rafter, 1899.
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett, 1899.
27. Operations at river stations, 1898, Part I, 1899.
28. Operations at river stations, 1898, Part II, 1899.
29. Wells and windmills in Nebraska, by Erwin Hinckley Barbour, 1899.
30. Water resources of the Lower Peninsula of Michigan, by Alfred C. Lane, 1899.
31. Lower Michigan mineral waters, by Alfred C. Lane, 1899.
32. Water resources of Puerto Rico, by H. M. Wilson, 1900.
33. Storage of water on Gila River, Arizona, by J. B. Lippincott, 1900.
34. Geology and water resources of southeastern S. Dak., by J. E. Todd, 1900.
35. Operations at river stations, 1899, Part I, 1900.
36. Operations at river stations, 1899, Part II, 1900.
37. Operations at river stations, 1899, Part III, 1900.
38. Operations at river stations, 1899, Part IV, 1900.
39. Operations at river stations, 1899, Part V, 1900.
40. The Austin dam, by Thomas U. Taylor, 1900.
41. The windmill: its efficiency and economic use, Part I, by E. C. Murphy, 1901.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gaging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. [Approved June 11, 1896; Stat. L., vol. 29, p. 453.]

The endeavor is made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or who have furnished data. Requests made for a certain paper and stating a reason for asking for it are granted whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent.

Application for these papers should be made either to Members of Congress or to

THE DIRECTOR, UNITED STATES GEOLOGICAL SURVEY, WASHINGTON, D. C.